

Quality Assurance Project Plan

for

Comparing eelgrass mapping capabilities across different remote sensing techniques in Massachusetts

Prepared by: Jill Carr

Massachusetts Bays National Estuary Partnership

Project period: 2021 - 2023

QAPP Approval Date: 05/03/2022

1. PROJECT MANAGEMENT

1.1 TITLE AND APPROVAL PAGE

Plan Title: Comparing eelgrass mapping capabilities across different remote sensing techniques in Massachusetts

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Effective Dates of Plan: October 2021 – December 2023

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**There are currently no EPA funds for this project which would require an approved QAPP. However, EPA has conducted a courtesy review and found that it contains the information that would make it "approvable" to support the project.*

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1.3 DISTRIBUTION LIST

Table 1. QAPP distribution list.

Name	Organization	Project Role	Email address & telephone number
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Todd Callaghan	MA CZM	QAPP review, data quality manager, reporting	Todd.callaghan@mass.gov ; 617-776-9409
As assigned	U.S. Environmental Protection Agency	Quality Assurance Officer	R1QAPPs@epa.gov
Tay Evans	MA Division of Marine Fisheries	Partner: Side scan sonar and diver survey field lead; Steering Committee member	Tay.evans@mass.gov
Lisa Rhodes	MA Department of Environmental Protection	Partner: Fixed-wing aerial imagery field lead; Steering Committee member	Lisa.Rhodes@mass.gov
Juliet Simpson	MIT SeaGrant	Partner: AUV aerial imagery field lead; Steering Committee member	simpsonj@mit.edu
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Table 2. List of Acronyms & Abbreviations

Abbreviation	Meaning
AUV	Autonomous Unmanned Vehicle (drone)
CCAP	Coastal Change Analysis Program (NOAA)
CCMP	Comprehensive Conservation and Management Plan
CMECS	Coastal and Marine Ecological Classification Standard
CZM	Massachusetts office of Coastal Zone Management
DEP	Massachusetts Department of Environmental Protection
DMF	Massachusetts Division of Marine Fisheries
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System
GPS	Global Positioning System
GSD	Ground Sample Distance
MassBays	Massachusetts Bays National Estuary Partnership
MITSG	Massachusetts Institute of Technology SeaGrant
MLLW	Mean Lower Low Water
MMU	Minimum Mapping Unit
NEP	National Estuary Program
NEU MSC	Northeastern University Marine Science Center
NOAA	National Oceanic and Atmospheric Administration
NSRWA	North and South Rivers Watershed Association
QA/QC	Quality Assurance and Quality Control
QAPP	Quality Assurance Project Plan
RGB	Red Green Blue
RMSE	Root Mean Square Error
SCUBA	Self-contained Underwater Breathing Apparatus
SSCW	Salem Sound Coastwatch
USACE	U.S. Army Corps of Engineers

1.4 PROJECT INTRODUCTION & ORGANIZATION

The project will be directed by MassBays and CZM, with field tasks and technical assistance by partners listed in Table 1, and project guidance from a multidisciplinary Advisory Committee (Appendix A). Funding for the project is provided by NOAA through a Project of Special Merit grant. Formally titled *Increasing agency confidence in eelgrass maps used for project review and ocean planning*, the project has the following goals: 1) assess the detection capabilities of four remote sensing eelgrass mapping techniques (side scan sonar, drone imagery, fixed-wing airplane imagery, and satellite imagery) as compared to diver surveys; 2) rank the methods by their ability to accurately detect sparse eelgrass and the meadow edge; 3) establish a process for integrating eelgrass maps derived from the various techniques (e.g., by determining appropriate buffers to apply to each dataset); 4) generate map products showing updated eelgrass estimates at study sites; and 5) formalize recommendations regarding survey methods and remote sensing data limitations for eelgrass mapping.

The primary point of contact will be Jill Carr of MassBays, with project management support and QA/QC review from Todd Callaghan of CZM. Pam DiBona will be responsible for grant management and deliverable sign-offs. Project partners DMF, SSCW, NEU MSC, and NSRWA are provided funding for field and/or data processing and analysis tasks and are also providing substantial match for technical services. DEP and MITSG are not receiving any funding but providing match via sharing imagery and technical services, respectively.

DEP will coordinate and oversee the fixed-wing manned airplane survey as a part of their existing routine survey program, which surveys one of five Project Areas per year on a five-year rotating cycle (Costello and Kenworthy 2011). The Planning Area for 2022 is from Duxbury to Cape Ann. Imagery will be collected and post-processed by DEP's contractors per their existing approved procedures. MITSG will be the field lead for all drone surveys, drawing on their previous experience executing drone surveys over eelgrass. DMF will lead all side scan sonar, underwater photo groundtruthing, and SCUBA-based dive surveys. Other partners will assist in the field as needed. Project partners MITSG, SSCW, NEU MSC, and NSRWA will further assist by interpreting remote sensing imagery for the purpose of eelgrass delineation. These partners will be thoroughly trained, and their image analysis will undergo QA/QC both within their organizations and by the project PI's. MassBays and CZM will also be responsible for data analysis and reporting. See Figure 1 for an organizational chart.

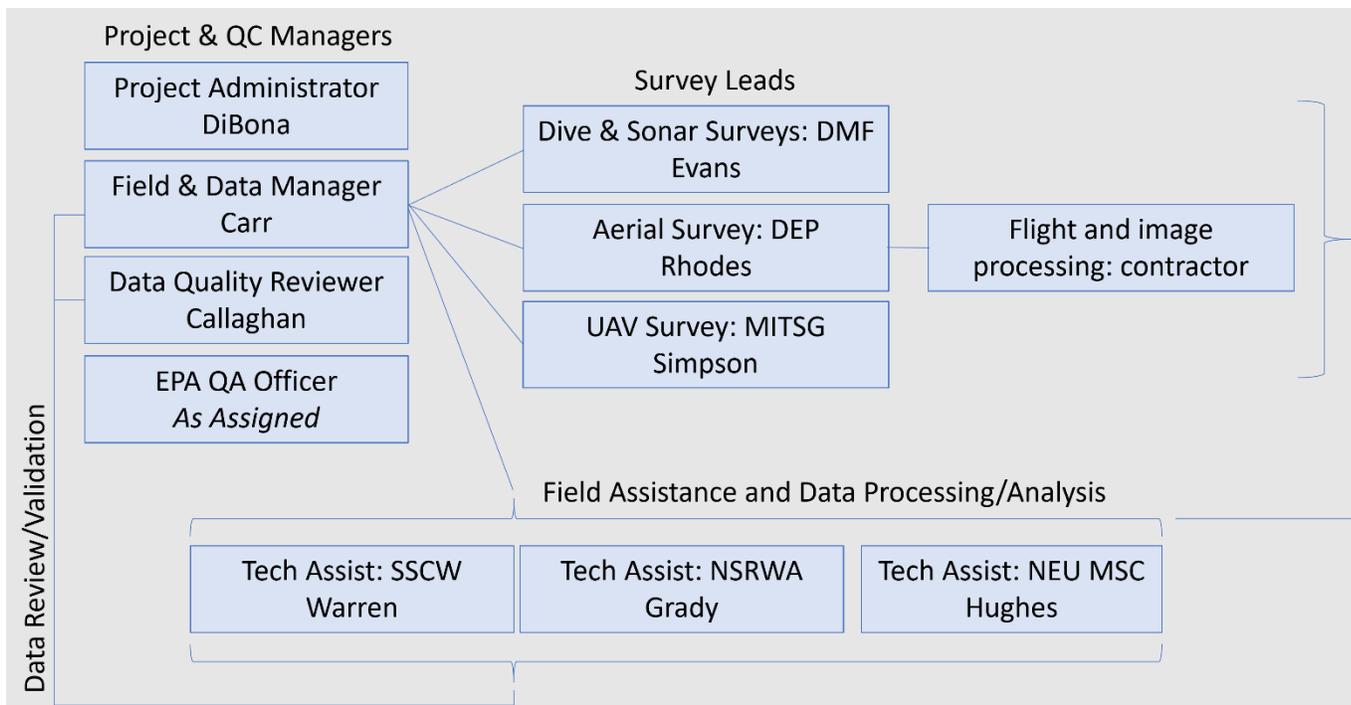


Figure 1. Organization Chart

MassBays will prepare the project QAPP and submit it to EPA for technical review and approval. EPA review will be a courtesy, as the project is not funded by EPA, however as an EPA National Estuary Program, MassBays will be using the results of the project to implement its EPA-approved CCMP. Any edits from EPA reviewers will be addressed, and the final approved version will be distributed for signatures and sent to project partners.

The principal users of the data from this project will be CZM, MassBays, DMF, DEP, EPA, project partners, and the greater eelgrass mapping and management community, including other NEPs and coastal management programs across the country. Project results and products will be made publicly available.

1.4.1 AMENDMENTS OR REVISIONS TO QAPP

This is a limited-term study (2021-2023), therefore amendments or revisions to the QAPP are not expected once approved. However, should the project expand to additional coastal areas beyond the scope of the current grant, requests for Amendments/Revisions will be made to EPA via email. Any changes that significantly affect the technical and quality objectives of the project will trigger a revision and re-approval of the QAPP.

1.5 PROBLEM DEFINITION/BACKGROUND

1.5.1 PROBLEM STATEMENT

Eelgrass (*Zostera marina*) meadows provide multiple ecosystem benefits in estuarine systems: they support biodiversity, attenuate wave energy, stabilize and oxygenate sediments, sequester carbon and nutrients, and filter the water column. Eelgrass meadows and smaller patches create important coastal habitat, providing shelter and forage for many commercially important marine fish species. DEP uses eelgrass extent and condition as an aquatic

health indicator under CWA §305(b) and 303(d) since it is acutely sensitive to anthropogenic and environmental stressors such as water quality impairment, physical damage, turbidity and rising sea temperatures. As a result of such stressors, and in addition to natural variations, eelgrass meadow density and extent can wax and wane considerably from year to year. Eelgrass extent is declining throughout its range, including in Massachusetts (Costello and Kenworthy 2011).

The Ipswich Bay, Massachusetts Bay, and Cape Cod Bay system (collectively “Massachusetts Bays”) is a federally-designated *Estuary of National Significance* under the Clean Water Act, and MassBays, as part of the NEP, utilizes eelgrass coverage as a state-of-the-system indicator of ecosystem integrity. MassBays’ CCMP focuses on eelgrass meadows as a vital habitat within the Bays ecosystem, and calls for expanded efforts to monitor and restore eelgrass beds (MassBays, 2019).

In Massachusetts, local, state, regional, and federal agencies rely heavily on remote sensing eelgrass mapping data for their assessments. Municipal Conservation Commissions, DEP, CZM, DMF, EPA, USACE, NOAA (specifically for Essential Fish Habitat consultations) and others use maps created by DEP from its fixed-wing manned aerial photography surveys. These flights cover a subset of the Massachusetts coast each year, providing nearly coast-wide maps approximately every five years. DEP’s project has the greatest coverage and longest time series of any efforts to track eelgrass extent and is therefore the most heavily utilized source of mapping data. Unfortunately, at a temporal resolution of once every five years, and imagery captured at a 1:20,000 scale, this program is not well-suited for tracking seasonal or inter-annual patterns within eelgrass meadows, especially in patchy dynamic meadows or in estuaries with poor water clarity. Further, there is a relatively high degree of uncertainty around the accuracy of meadow edge delineations performed at this scale, both at the shallow and deep edges. While the DEP survey does include some boat-based underwater photo groundtruthing to confirm signatures in the imagery, resources are limited and detailed meadow-edge groundtruthing is not feasible at DEP’s planning area scale. Still, it is important to know if and by how much this heavily relied-upon dataset underestimates the meadow.

To supplement DEP data with higher temporal and spatial resolution eelgrass maps, various entities carry out *ad hoc* mapping efforts for their own purposes: DMF and academic researchers conduct side scan sonar surveys and SCUBA surveys at particular areas of interest, EPA Region 1 is studying the use of high-resolution imagery acquired from satellites for mapping eelgrass and abundance (Keith et al. 2019), and academic institutions have used consumer-grade drones in experimental mapping projects. Several nonprofit watershed groups use underwater cameras, snorkelers, and GPS to map and track changing conditions in local meadows. The edge-detection accuracy for all these methods is currently unknown, thus is it difficult to interpret results or integrate cross-method survey data.

1.5.2 PROJECT / TASK DESCRIPTION

This project will acquire imagery using four remote sensing eelgrass mapping methods (side scan sonar, drone imagery, fixed-wing airplane imagery, and satellite imagery) and will conduct diver transect surveys and boat-based underwater photo groundtruthing surveys. Eelgrass maps derived from the remote methods will be compared to the diver and photo groundtruthing surveys to evaluate how each remote method performs in mapping areas of low eelgrass density and the meadow edge. The project approach includes planning, field surveys, data analysis and reporting components.

A project Steering Committee comprised of project partners will convene to confirm roles, set project schedules, and provide QAPP input. A project Advisory Committee, comprised of local and regional remote sensing and eelgrass mapping experts, will convene to provide technical guidance on site selection, survey methods and data analysis procedures.

A description of the core tasks for this project are outlined in Table 3 below, along with a generalized timeline, capacity, milestones, outcomes and products.

Table 3. Task details

Task 1 – PLANNING	
Task 1a	Planning: Project kick-off and QAPP development
Timeframe	Oct - Dec 2021
Description of Activities	Convene steering and advisory committees to develop schedule, roles and fine-tune methods, begin to develop QAPP with input
Program Capacity	The P.I.'s routinely convene stakeholders and collaborators on various projects, and are seen as experts in the development of QAPPs
Milestones	Host committee meetings, distribute meeting minutes, project schedule and roles
Date of Completion	Hold meeting before 12/15/21
Outcomes	Project is on track to start
Final Products	Meeting minutes, project schedule, draft QAPP
Task 1b	Planning: Survey preparation
Timeframe	December 2021 – April 2022
Description of Activities	Finalize QAPP. Engage partners to identify specific field schedules. Select satellite image capture dates, coordinate with DEP on aerial survey schedule
Program Capacity	PI's have managed survey preparation in the past. PI Carr holds a M.S. in GIS and has the capacity for GIS-based site selection work
Milestones	Set survey dates, determine equipment needs, purchase equipment
Date of Completion	May 1, 2021
Outcomes	Survey plans are formalized
Final Products	Calendar of field activities, schedule for image acquisition, and equipment inventory
Task 2 – FIELD SURVEYS	
Timeframe	May 2022 – June 2022
Description of Activities	Conduct side scan sonar, aerial, and drone surveys at each of five sites, diver ground-truthing within the same 2 weeks. Archive, back up data at close of each field day
Program Capacity	Partners (DMF, NUMSC) and PI Carr have expert experience conducting side scan sonar and diver surveys in eelgrass habitat. DMF and NEU MSC have sanctioned dive programs to support dive work. Partners (DEP) have expert experience flying fixed-wing aerial surveys over eelgrass. PI and partner (MITSG) are drone pilots with eelgrass mapping experience.
Milestones	Surveys are conducted at the five project sites in the targeted two week time period, survey data are successfully collected
Date of Completion	September 1, 2022
Outcomes	All sites surveyed as planned, all datasets complete
Final Products	Side scan sonar imagery, aerial imagery, and underwater data records
Task 3 – DATA ANALYSIS	
Timeframe	September 2022 – December 2022

Description of Activities	Purchase satellite imagery; train partners to interpret aerial, satellite, and side scan imagery in ArcGIS for eelgrass extent. Compare polygons against photo groundtruthing point data and diver transect data. Conduct geospatial analyses for detection capabilities and errors. Data management per the plan.
Program Capacity	DEP and DMF routinely process aerial and sonar imagery, respectively, for optimal interpretation. Other partners will be trained and assist in interpreting all 4 modes of imagery for eelgrass signature, and those partners have the necessary mapping software and scientific staff.
Milestones	Obtain compiled satellite imagery, DEP aerial imagery and sonar mosaics by end of October to provide time for image analysis. Conduct image-interpreter training (November). Finalize eelgrass polygons and analyze against diver-based ground-truthing data to generate final maps and buffers (December).
Date of Completion	January 1, 2023
Outcomes	Field surveys are completed, data management plan is implemented
Final Products	Geodatabase containing all survey data, polygon shapefiles of eelgrass meadows delineated for each survey method, spatial analysis of edge detection capabilities of each method at each site, map of buffers for each method.
Task 4 – REPORTING	
Timeframe	January 2023 – March 2023
Description of Activities	Prepare executive summary and a final report including findings and recommendations. Conduct outreach to regulators, resource managers, other CZMs and NEPs, municipalities and consultants to share findings. Use established means to reach target audiences.
Program Capacity	PIs have extensive experience preparing scientific reports for both technical and general audiences, as well as presenting in a variety of settings. PI Callaghan is extensively networked to extend outreach to other CZMs and resource managers.
Milestones	Submit final report and circulate memo by February 1. Present at EPA’s Eelgrass conference in March and MACC conference in April. Other conferences and outreach venues to continue beyond.
Date of Completion	April 30, 2023
Outcomes	Broad dissemination of findings and recommendations
Final Products	Final report, agency memo, presentation slides

1.5.3 SITE SELECTION

Each of the survey methods will take place at each of five study sites (Figure 2, Table 4). Site selection is constrained by DEP’s planned aerial survey area for 2022 (from Kingston to the NH border), presence of known eelgrass meadows, and accessibility (e.g., nearby boat launch for boat-based survey, no obstructions for side scan sonar survey, nearby public lands from which to operate drones). Beds known to have very sparse, patchy cover throughout the meadow will be avoided, as will those known to be in areas of chronic turbidity. More detailed site maps showing eelgrass and bathymetry can be found in Appendix B.



Figure 2. Map of study sites (red stars) along the northern coast of Massachusetts. Eelgrass areas are shown in green (MassDEP, 1995 layer) and bathymetry gradient in blue.

Table 4. Site details. Approximate mean depths use the most recent MassDEP eelgrass layers and NOAA Raster Nautical Charts available in ArcGIS Online.

Site	Approx. meadow center Lat/Long	Access Plan	Approx. MLLW Depth (ft) at shallow edge using most recent DEP map on NOAA chart	Approx. MLLW Depth (ft) at deep edge using most recent DEP map on NOAA chart
Niles Beach, Gloucester	42.59606, -70.65612	Public parking and foot access from 20 Eastern Point Blvd; boat launch at Annisquam River landing	2	15
Mingo Beach, Beverly	42.54923, -70.83939	Public parking and foot access from Hale Street (route 127); boat launch at Annisquam or Salem Willows	2	15
Swampscott Harbor	42.46606, -70.91019	Public parking and foot access to Fisherman’s Beach from Humphrey St (route 129); boat launch at Salem Willows or Winthrop Harbormaster ramp	3	7
Dorothy Cove, Nahant	42.41999, -70.91606	Parking and access with permission (TBD) from Nahant Dory Club at 0 Wharf Street. Alternate access plan involves permission from neighbor. Boat launch at Winthrop Harbormaster ramp or Blossom Street ramp in Lynn.	3	15
Cohasset Harbor	42.25169, -70.77619	No foot access; local NGO CSCR will facilitate a drop-off to Hog Rock using their skiff; boat launch at inner Cohasset Harbor.	1-2	6

1.6 DATA QUALITY OBJECTIVES AND CRITERIA

This project compares numerous remote sensing survey techniques against diver survey data. All of the surveys involve collection of spatial data (e.g., geographically-referenced imagery, boat-based GPS coordinates). Each dataset will be deemed Fit for Use if the criteria are met and the data are able to be used for the intended purpose. If criteria are not met, data will be qualified and either used with a disclaimer of their shortcomings or omitted from the analysis if necessary. For example, drone imagery can be difficult to georeference over deeper water, where benthic signatures are less visible and software has trouble creating image mosaics. If one of the drone datasets is deemed incomplete because only the shallow edge was able to be mapped, it may be acceptable to proceed using only the shallow imagery. In other cases, the data may be unusable, for

example, if unanticipated cloud cover or choppy waves obscure visibility through the water. Data quality indicators, criteria, and appropriate protocols are described separately for remote sensing surveys, diver surveys, and the photointerpretation process in Tables 5, 6 and 7.

Table 5. Data Quality Indicators, Criteria, and Quality Control Protocols for **remote sensing surveys**

Data Quality Indicator	Criteria	Protocol
<p>Imagery Completeness</p>	<p>Imagery completeness can be thought of both in terms of areal extent of the imagery and in terms of coverage within the survey area (e.g., individual image tiles are successfully mosaicked together and not missing from the mosaic). Understanding that environmental conditions can affect both measures of completeness, in some cases unexpectedly, we must anticipate and allow for less than 100% imagery completeness. For all survey types, imagery shall be considered complete if it covers and is usable (e.g., absent of cloud or glare obstructions) $\geq 80\%$ of the study area. For drone and side scan sonar imagery, which are collected as small individual tiles that must be mosaicked together, fewer than 25% of individual tiles shall be missing. It is important to note that in order to run the intended analyses, imagery must not be missing or obscured at the three diver transect locations at each site.</p> <p>There are additional criteria for side scan sonar and drone imagery completeness to ensure successful mosaicking and eelgrass visibility. In the vicinity of the diver transects, the side scan sonar survey will be conducted in two differently oriented “mow the lawn” patterns, one that runs parallel and one perpendicular to shore, with each line overlapping the adjacent line by $\geq 50\%$. Beyond the diver transect areas, a single survey pattern parallel to the depth contours and without overlap will suffice. The use of two opposing patterns improves eelgrass visibility in the event it is laying down in the current or casting shadows in the imagery, issues that are especially problematic in low-density edge areas. Drone imagery will be collected with $\geq 50\%$ side and front overlap to improve image mosaicking success. Underwater photo groundtruthing will result in unobstructed digital photos with minimal turbidity for 80% of the targeted locations (target</p>	<p>When planning for implementation of each survey type, the criteria will be incorporated into the field plan. Image coverage will be checked during and immediately after each field survey where possible, and adjustments will be made in the field as needed.</p> <p>The areal extent and coverage of imagery within the survey area will be compared to criteria. Field collection criteria for side scan sonar and drone surveys will be compared to field logs and actual imagery coverage. If any dataset is considered incomplete, it may be qualified or dropped from the analysis per Section 4.6. The Data Review Evaluation form will be used to document if criteria are met.</p>

	<p>is 30 locations per site)</p>	
<p>Imagery Resolution & Quality</p>	<p>Ground Sample Distance (GSD; the distance between pixels in the image on the ground) varies by data source but will be minimized as much as possible for each survey method. For imagery over flat surfaces (e.g., water surface, seafloor), GSD is approximately equal to spatial resolution (i.e., pixel size). These terms will be used interchangeably for this project. Satellite imagery with < 5 m GSD will be targeted for purchase; ideally aiming for < 1 m. Drone imagery will be < 5 cm GSD. Side scan sonar resolution is < 50 cm GSD. DEP's aerial imagery will be < 1 m GSD.</p> <p>All imagery will be free of defects and color flaws that affect visibility of the target habitat. Underwater photo groundtruthing imagery will be of high enough quality to classify habitat cover types.</p>	<p>GSD will be reported in with the metadata for each survey type.</p> <p>The Data Review Evaluation form will be used to document if criteria are met.</p>
<p>Comparability</p>	<p>Field observations and imagery are collected using protocols standardized across all sites (Section 2).</p> <p>For photo groundtruthing survey, observer error is minimized when estimating eelgrass percent cover.</p>	<p>Confirm that protocols from this QAPP were used in the field, and no changes were made.</p> <p>If more than one observer is assigning the % cover bin during photo groundtruthing, quality control samples will be collected at 10% of the sampling locations. To be deemed consistent, percent cover bins must be the same or adjacent bins (e.g., observer 1 selects 20-30% and observer 2 selects 30-40%). The Data Review Evaluation form will be used to document if criteria are met.</p>

<p>Spatial Accuracy</p>	<p>Horizontal position accuracy error for each imagery dataset will be ≤ 3 meters.</p> <p>Horizontal accuracy of GPS coordinates (collected for photo groundtruthing survey) will be ≤ 3 m, the approximate accuracy of a marine GPS unit.</p> <p>Vertical accuracy will not be evaluated, as elevation and bathymetric data collection are outside the scope of this work.</p>	<p>The remotely-sensed positions of at least 10 locations visible in the imagery datasets will be checked against known coordinates using 2021 USGS Color Orthoimagery as a reference dataset (not applicable to sonar data). Horizontal accuracy will be recorded with the metadata for each survey type.</p> <p>Deviations will be noted and corrected where possible using image georeferencing tools. The Data Review Evaluation form will be used to document if criteria are met.</p>
<p>Environmental & Timing Conditions</p>	<p>Field surveys will meet environmental & timing conditions described in the literature for image collection over eelgrass: Low tidal stage, sun angle 15-30°, cloud cover <10%, wind <10 km/h, wave height < 0.5 m, low turbidity, and recent calm weather (NOAA CCAP, Nahirnick et al. (2019), Doukari et al. (2019), and Joyce et al. (2018)).</p> <p>Secchi disk data collected on the side scan sonar and diver survey days will help describe water clarity conditions at each site. Note however that secchi sampling events may not be simultaneous with the aerial imagery surveys and are intended to provide qualitative context only.</p> <p>While the goal of the project is to conduct all surveys within 2 weeks of one another to limit temporal effect on eelgrass edge location or density, it is important to build in flexibility for major storm and unexpected environmental conditions. Thus, data can still be used if no more than 3 weeks passed between any given survey type.</p>	<p>Exact date and time of each field survey will be based on the environmental criteria. The Field and Data Manager, along with field crew leads, will use resources in Section 2.7 to guide field plans. For satellite imagery purchase, the criteria will be used to search for and select appropriate imagery.</p> <p>During collection the actual date, time and environmental conditions will be logged and recorded on the Eelgrass Survey Metadata Log.</p> <p>After collection, actual conditions will be compared to criteria; images will also be inspected for cloud shadow, waves and water clarity. The Data Review Evaluation form will be used to document if criteria are met.</p>

<p>Fitness for Use</p>	<p>The remote sensing datasets will meet the criteria above and will be suitable for the intended purpose.</p>	<p>Imagery completeness, resolution, quality, accuracy, and timing will be compared against criteria, and fitness for use will be documented for each dataset from each site, using the Data Review Evaluation form.</p> <p>Data that do not meet the criteria will be qualified and either used with a disclaimer or omitted from the analysis if necessary.</p>
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Table 6. Data Quality Indicators, Criteria, and Quality Control Protocols for SCUBA diver Surveys

Data Quality Indicator	Criteria	Protocol
Spatial accuracy	Field GPS units used to collect diver transect location coordinates will have a reported accuracy error ≤ 3 m	Check reported accuracy of individual field GPS units against criteria
Completeness	Divers collect quadrat-level eelgrass data at $\geq 80\%$ of the designated quadrat locations (target is 12 quadrats per transect) and 100% of the planned transects are visited (3 per site). Fewer than 10% of quadrat data records have missing parameter data, per the field datasheet (Appendix F).	Survey completion is checked in real time during field surveys. If any transects or sites are incomplete, they are revisited and completed within the 2 week time period. The Data Review Evaluation form will be used to document if criteria are met.
Comparability	Field observations are collected using a standardized protocol across all sites and all transects (Section 2.6). Ideally, diver surveys are performed within 2 weeks of remote surveys to maximize comparability between survey types. Up to 3 weeks is acceptable if hazardous weather limits survey opportunities. Observer error will be minimized.	Confirm that protocols from this QAPP were used in the field, and no changes were made. At one quadrat per transect, both divers collect all the required parameters to allow for QC review of diver data and to ensure consistency among divers. To be deemed consistent, percent cover bins must be the same or adjacent (e.g., diver 1 selects 20-30% and diver 2 selects 30-40%);

		canopy height must have \leq 20% relative percent difference and categorical data (algae presence, eelgrass distribution type) must match. The Data Review Evaluation form will be used to document if criteria are met.
Representativeness	Field observations are made at planned locations that represent various meadow conditions, so that sites are representative of the greater eelgrass community in northeastern Massachusetts.	Ensure survey teams have correct and detailed site information prior to survey. Check actual survey site locations against planned locations and report any variances.

Table 7. Data Quality Indicators, Criteria, and Quality Control Protocols for **Photointerpretation**

Data Quality Indicator	Criteria	Protocol
Mapping completeness	The meadow at each study site is mapped with a polygon created in ArcGIS.	Extent of mapped eelgrass will be compared to size of study area to ensure completeness.
Interpretation accuracy	Areas of eelgrass presence or absence visible in remote sensing imagery are accurately classified.	Interpreters complete training and pass skill evaluation, where relative percent difference (in eelgrass acreage) between trainee’s and trainer’s delineation is \leq 20%. For real interpretations, two interpreters work together to establish polygons, and PI’s do final QA/QC on all interpretations
Interpretation rules are applied	Remote imagery will be interpreted at the highest resolution possible for the dataset, mapping any visible eelgrass patch regardless of size (e.g., no MMU applied), following all other photointerpretation rules (Table 11).	Interpreters will document adherence to the rules, and report any variances. Problematic areas in the imagery will be flagged for additional QA/QC.

Spatial Accuracy	Interpreters use appropriate coordinate system and datum when drawing polygons. While drawing, interpreters keep their line as close to the feature as possible.	Datum and coordinate system are confirmed prior to starting interpretation work. Interpreters continually check their polygons and fix vertices that are too far from the visible feature.
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1.7 DOCUMENTS AND RECORDS

MassBays will prepare the QAPP and submit it to EPA for courtesy approval. When approved, MassBays will circulate the QAPP to the parties listed in Table 1. The QAPP Preparer will be responsible for assuring that all parties and project personnel have the most recent version of the QAPP, any amendments to the QAPP, and any updates.

Documents and data records collected under this QAPP will be retained by MassBays and other project partners as described in Table 8.

Table 8. Document and record retention information.

Document/Record	Location	Retention	Format
QAPP	MassBays, CZM	Indefinitely	Electronic
Survey plan & logs	MassBays, CZM	Indefinitely	Electronic
Field data sheets	MassBays, CZM, DMF, DEP, MITSG	Indefinitely	Electronically scanned paper copies
Individual orthoimagery tiles	MassBays, CZM, DMF, MITSG	Indefinitely	Electronic
Final georeferenced mosaic imagery	MassBays, CZM, DMF, DEP, MITSG	Indefinitely	Electronic; ArcGIS Online
GIS files	MassBays, CZM	Indefinitely	Electronic
Underwater and field photo files	MassBays, CZM, DMF	Indefinitely	Electronic
Final report	MassBays, CZM	Indefinitely	Electronic

2. MEASUREMENT AND DATA ACQUISITION

Five survey methods will be conducted at each of five survey sites. While given its own section below, the photo groundtruthing survey is considered an integral component of the remote sensing surveys and not an independent method being evaluated by this study. For each field and image acquisition activity, a Metadata Log will be completed, documenting environmental conditions and equipment specifications during the activity. For side scan sonar, photo groundtruthing, and diver surveys, additional field datasheets will be completed to record measurements. All logs and datasheets can be found in Appendix F. The protocols for each survey are described below.

2.1 AIRPLANE AERIAL SURVEY

DEP will coordinate and oversee the fixed-wing manned airplane survey as part of their existing Eelgrass Mapping Project, which has conducted aerial surveys over each of their Planning Areas every five years since the early 1990s. Flight planning and image collection will follow established DEP and NOAA Coastal Change Analysis Program protocols (Costello and Kenworthy 2011, Dobson et al. 1995, Finkbeiner et al. 2001), and DEP's Standard Operating Procedure (Appendix C). Digital imagery will be collected at a scale of 1:20,000 with +/- 3 m ground position accuracy. Imagery will be post-processed into geo-rectified mosaics by DEP's contractors as part of their contract and delivered to the Field and Data Manager to coordinate eelgrass interpretation.

Flights over the 2022 Planning Area, from Cape Ann to Kingston, will take place in late May or early June 2022. Early daytime low-tide flight windows will be targeted, with the most likely flight window being between May 18th and 21st between 8am and 10am. If weather conditions preclude flights during that window, dates into June will be selected. The peak growing season for eelgrass in New England is between June and September. In the earlier portion of that range, water quality tends to be more favorable for image collection, with lower water temperatures and less algal growth. For that reason, DEP targets late spring and early summer, and thus the same time will be targeted for all five survey methods. The dates of all other surveys will be based on a 2-week window inclusive of DEP's survey dates.

The DEP program historically collected True Color photography on film but has evolved to digital multispectral image collection. Flight and environmental specifications have not changed: imagery is collected at low tide, low sun angle, and with minimal wind and cloud cover. Imagery is collected from sensors affixed to the gear leg or the underside of a small aircraft such as a Cessna. A GPS-supported navigation system will interface with the camera control software, differential-GPS, and inertial measurement unit sensors to capture horizontal positional data. Raw images are radiometrically and geometrically corrected using the camera's calibration files. Images are mosaicked together, and final orthomosaics are produced in horizontal projection NAD1983 (2011) State Plane Massachusetts Mainland FIPS 2001 (Meters). Spatial accuracy of the imagery is within +/-3 m of positions on the ground.

2.2 SATELLITE

Free, publicly available satellite imagery exists (e.g., Landsat imagery available through the USGS Earth Explorer), however the resolution (30 m) and overpass frequency (16 days) are not optimal for this project. Instead, the project will utilize commercial satellite imagery sourced from one of several potential retailer websites, such as:

- <http://worldview3.digitalglobe.com/>
- <https://www.planet.com/>
- <https://imagehunter.apollomapping.com/>
- <https://www.spymesat.com/>

Other commercial outfits like Maxar, SIIS, SOAR, URSA, and others will also be considered, as their network of small satellites provide almost daily overpass frequency and at high resolution (<1 m on some platforms). Image archives will be searched and filtered for the best available imagery over the study sites that meets

the environmental conditions needs, including date time of image (to target low tide), low or no off-nadir (in degrees, close to 0° as possible), resolution ≤ 1 m if possible, 0% clouds, and no solar glare.

This project will not involve the cost prohibitive tasking of satellites, which could more precisely target the desired dates, times and locations by sending satellites out on targeted missions. Instead, weather and marine conditions will be closely monitored within the 2-week survey period to identify optimal image dates and archived imagery will be sought for dates that had optimal conditions.

Image processing is expected to be minimal for satellite imagery, which comes georectified and color balanced upon purchase. Minor processing steps could include projecting imagery into the same datum as all other project datasets (NAD83), and evaluating different histogram stretches to optimize underwater feature visibility. A Natural or True Color band combination (red, green, blue bands) will be used, which most closely replicates what the human eye can see.

2.3 DRONE

MIT SeaGrant will lead all drone field surveys, which will utilize off-the-shelf consumer drones (e.g., DJI Phantom series). Drones will be operated by licensed Remote Pilots following all FAA regulations. Notification and/or approval processes will be followed for any sites near airports or in other controlled airspace, and onshore flight staging will take place on public lands or private lands with owner approval.

The proprietary DroneDeploy application will be used for flight planning and management, including automated route planning, launch, survey, and recovery. Flight altitude will be set to 80 m, found in the literature to be optimal for seagrass mapping (Nahirnick et al. 2019, Doukari et al. 2019, Joyce et al. 2018) with 75% front overlap and 65% side overlap of adjacent image tiles. At 80 m elevation, a 30-acre site can be mapped in about 15 minutes, collecting approximately 230 images at 1.8 cm (0.7 inch) per pixel resolution.

The process of mosaicking stitches together individual image tiles in a way that seamlessly joins and color-balances image edges while geometrically correcting lens distortion and the perspective of the camera relative to objects in the image. Various softwares can perform this step by using embedded information about the camera's location, elevation, and field of view, along with matching objects (i.e., tie points) detected in overlapping adjacent images. For this project, individual image tiles will be mosaicked using either a) the mosaic functions built into DroneDeploy's proprietary software, or b) using the ESRI Drone2Map add-in for ArcGIS. Resulting orthomosaics will have 5 cm resolution or better. Images will be in Natural Color, as multispectral sensors are not standard equipment on off-the-shelf drones and are not part of the project scope.

This project does not propose the use of ground control points (GCPs), which are markers of known coordinates that can be detected in the imagery and can improve horizontal accuracy when placed in the field prior to aerial surveys. The logistics of deploying and then recovering meaningful GCPs at each of five sites, in a dynamic marine environment, and meeting the timetables for all the various remote surveys, are unfeasible. In lieu of GCPs, the 2021 USGS Color Orthoimagery available on MassGIS will be used to visually compare horizontal accuracy between drone imagery and USGS Orthoimagery. Previous work done by the project lead Carr found extremely high agreement between drone and USGS imagery (unpublished data). USGS orthoimagery includes statewide 4-band (RGB-IR) coverage at 15 cm resolution. The data were developed based on horizontal projection/datum NAD 1983 2011 UTM zone 19N, and have horizontal

accuracy of 10 cm Root Mean Square Error (RMSE)(MassGIS). It should be noted that absent GCPs, it is possible for users to manually extract ground control points using features visible in high resolution orthoimagery by tying them to features in the drone imagery, and this method will be used if visual comparison finds drone horizontal accuracy to be off by >1 m.

A common challenge with drone image collection over water is the ability of the mosaicking software to detect tie points between individual image tiles over largely homogeneous open, featureless water. Images are collected at low flight elevation, making it difficult to capture the target aquatic habitat as well as nearby landforms, islands, structures, etc. Tie points are easily generated where beaches, rocks and islands are present, or where there is high contrast between seafloor habitats visible through the water column (e.g. bright sand against dark vegetation makes both features more detectable). Usually not a problem in shallow water, tie point generation becomes more problematic over deeper water, where less sunlight reaches the bottom and visibility is reduced. If an adequate number of tie points between adjacent images cannot be calculated, image tiles are dropped from the mosaic resulting in data gaps. It is possible to manually tie dropped tiles back in, however, it is extremely time consuming, prone to user error, and requires additional processing to geographically correct for lens and perspective distortions. To mitigate data gaps related to deep-water tie point generation, the project will target optimal weather conditions described in Table 5, and target locations that are not subject to chronic turbidity.

2.4 SIDE SCAN SONAR

DMF will conduct all side scan sonar imaging using a Humminbird HELIX9 or similar side scan sonar system, following their established Standard Operating Procedure (Appendix D). The unit will be mounted to the hull of a small, motorized research vessel to run transects throughout the bed in a “mow the lawn” pattern. In the vicinity of the diver transect locations, side scan transects will be completed in two orientations (e.g., along survey lines parallel and perpendicular to shore), with adjacent swaths overlapping $\geq 50\%$, to achieve >200% imagery coverage in these focal areas. The rest of the meadow does not necessitate the same intensity of mapping data and will have $\geq 50\%$ coverage. Increasing coverage in the project focal areas is intended to account for the effects of currents on the lean of the canopy (e.g., upright, or laying down in the direction of flow), which can make the eelgrass signature more difficult to interpret and can cause shadows, especially in edge areas.

The side scan sonar survey collects a large volume of individual image tiles to the left and right sides of the vessel during each transect. Individual tiles will be processed, slant-corrected and mosaicked by DMF using the proprietary software SonarTRX. Any dropped tiles (data gaps) will be manually tied in. In focal areas where more than one transect orientation was used, eelgrass visibility in each mosaic will be assessed and the superior mosaic will be used for photointerpretation. All resulting mosaics will have approximately < 50 cm resolution. More detailed data processing steps are described in Appendix D.

2.5 UNDERWATER PHOTO GROUNDTRUTHING

Using a quadrat-mounted underwater camera, eelgrass presence/absence and percent cover will be field verified at each site following a modified version of the DMF SOP for Citizen Science Eelgrass Monitoring (Appendix E). The method includes the collection of Secchi disk measurements (collected between 10 AM and 4 PM or peak daylight) and underwater photography within a standardized 0.25 m² quadrat (also called a

drop frame). Eelgrass presence, percent cover and sediment type are recorded. Since the protocol is intended for embayment-wide monitoring, some modifications will be made to scale it down to site-level work. Rather than a stratified random site selection process, the survey crew will haphazardly sample at least 30 locations in the vicinity of the diver transects (i.e., within 25 m to either side), with the goal of sampling across the gradient of eelgrass coverage from the dense meadow to the sparse edge in order to detect areas of change along the gradient. At each of the 30 sample locations, the drop frame will be lowered to the seafloor and at least one underwater photo will be captured, assessed in real-time, and saved. Eelgrass percent cover will be determined visually on screen and a value will be assigned using CMECS Fine Percent Cover Value bins, which will be modified to include a 0% value, and 10% increments between 1-100% (Table 9, Fig 3). Total sample size will be 450 photo quadrats across all sites.

Table 9. CMECS % Cover bins

Figure 3. Examples of bins

Coarse Percent Cover Values	Fine Percent Cover Values	Examples of bins			
Trace	< 1%	1 to <10%	20 to <30%		
Sparse (1 to < 30%)	1 to < 10%	50 to <60%	70 to <80%		
	10 to < 20%				
	20 to < 30 %				
30 to < 40 %					
Moderate (30 to < 70%)	40 to < 50 %	50 to <60%	70 to <80%		
	50 to < 60 %				
	60 to < 70 %				
	70 to < 80 %				
Dense (70 to < 90%)	80 to < 90%	50 to <60%	70 to <80%		
	90 to 100%				
Complete	90 to 100%			50 to <60%	70 to <80%

The field verification points will later be integrated into the geospatial analysis process as accuracy assessment points, as described in the analysis section.

The camera affixed to the drop frame stores all images on an SD card. DMF will provide the survey kit (camera, drop frame, etc.) and blank SD cards for each sampling day. Images from the SD card will be delivered to PI Carr within one week of sampling. All field activities will be adequately and consistently documented to ensure defensibility of any data used for decision-making and to support data interpretation.

2.6 DIVER SURVEY

DMF will conduct SCUBA-based dive surveys to inform edge-detection capabilities of the remote sensing surveys and to catalogue eelgrass morphology at each site, with transect sampling at pre-selected near-edge locations. Divers will collect eelgrass percent cover, distribution type and canopy height data within 12 standardized 0.25 m² quadrats, along with underwater photographs, along two shallow and one deep transect at each of the five sites. This will result in 15 transects (10 shallow, 5 deep), with at least 12 quadrats per transect (n=180 quadrats total).

Not all edge areas are the same. Depending on geomorphological characteristics, the edge may be abrupt (i.e., where the meadow meets a high-energy surf zone or steep changes in bathymetry) or it may be very gradual. For this reason, transect lengths will be variable; but transects will be at least 50 m, and no longer than 100 m in length. Beyond 100 m, divers are unlikely to finish the transect in a single dive.

The field protocol will involve navigating to the pre-selected transect start location, which will be in a dense but near-edge portion of the bed. Selection of the start location and transect heading perpendicular to shore will be based on available aerial imagery (e.g., USGS 2021 orthoimagery, Google satellite imagery) and groundtruthed in the field. A bottom-anchored surface buoy will be deployed at the start location, and the survey crew will use an underwater camera to perform reconnaissance in the vicinity of the buoy to ensure it is in an appropriate location, and will tow the camera landward (or seaward, if at a deep-edge transect) to get an understanding of the meadow characteristics along the transect. If the transect will be too long (> 100 m) to reach low-density edge areas, the start point can be adjusted more landward (or seaward for deep-edge transects). Once the start location is deemed suitable, divers will confirm that the pre-determined transect heading is perpendicular to shore. At the seafloor, they will clip a transect reel to the surface buoy anchor and follow the heading until finding the last shoot, where they will deploy an additional bottom-anchored surface buoy. The last shoot is the most landward (or seaward) shoot perpendicular to shore found along a transect. When divers find what they believe to be the last shoot, they will confirm it by swimming 20 m beyond (Fig 4). This methodology has a potential flaw, where individual shoots >20 m away may go undetected, and the edge of the meadow under-represented. Such sparse individual shoots are unlikely to be detected reliably by any survey method and are therefore considered an acceptable loss in the scope of this project, which must strike a balance between diver resources and knowledge gained. After marking the last shoot along the transect, divers will then survey the transect at 12 evenly-spaced quadrats (e.g., if the transect is 100 m, a quadrat is placed approximately every 8 m). In each quadrat, divers will record eelgrass percent cover (Table 9, Fine bins), distribution type (Table 10), canopy height, note algae and animals to genus level, and collect a photo of each quadrat following the SeagrassNet protocol (Short et al. 2006). Divers will apply the definitions in Table 10 during transect surveys. At one quadrat per transect, both divers will collect all the required parameters to allow for QC review of diver data and to ensure consistency among divers.

Table 10. Definitions and methods to be applied during dive survey

Eelgrass Meadow	Eelgrass of any density is considered part of the meadow, up to and including the last shoot (e.g., the deepest or shallowest occurring shoot)
Distribution type	The degree of vegetation contiguity or proximity, measured in distance between shoots and/or patches, where: <i>Continuous distribution</i> has a distance <1 m <i>Transitional distribution</i> has a distance 1-5 m <i>Patchy distribution</i> has a distance >5 m
Last shoot	The most landward or seaward shoot that is <20 m away from the last observed shoot along a transect

Percent cover	A proxy for shoot density; the proportion of a hundred parts of a given area (0.25 m ² quadrat) that has plants present. Reported as 0% if absent, and in 10% bins from 1-100% if present (Table 9).
Canopy height	The substrate-to-leaf-tip height (cm) of a collective representative sample of shoots within a quadrat, ignoring the tallest 20%. This measurement is taken in situ by fanning or clumping shoots up into the water column against a meter stick and does not involve shoot collection.

On the boat, GPS coordinates will be collected at the start and end (last shoot) locations as marked by the surface buoys. Spatial accuracy of transect locations will be <3 m (likely closer to <1 m), the accuracy of most boat-based marine GPS units.

Before or after diver surveys, Secchi disk depth measurements will be recorded at each of the three transect locations per site, following the protocol described in Appendix E.

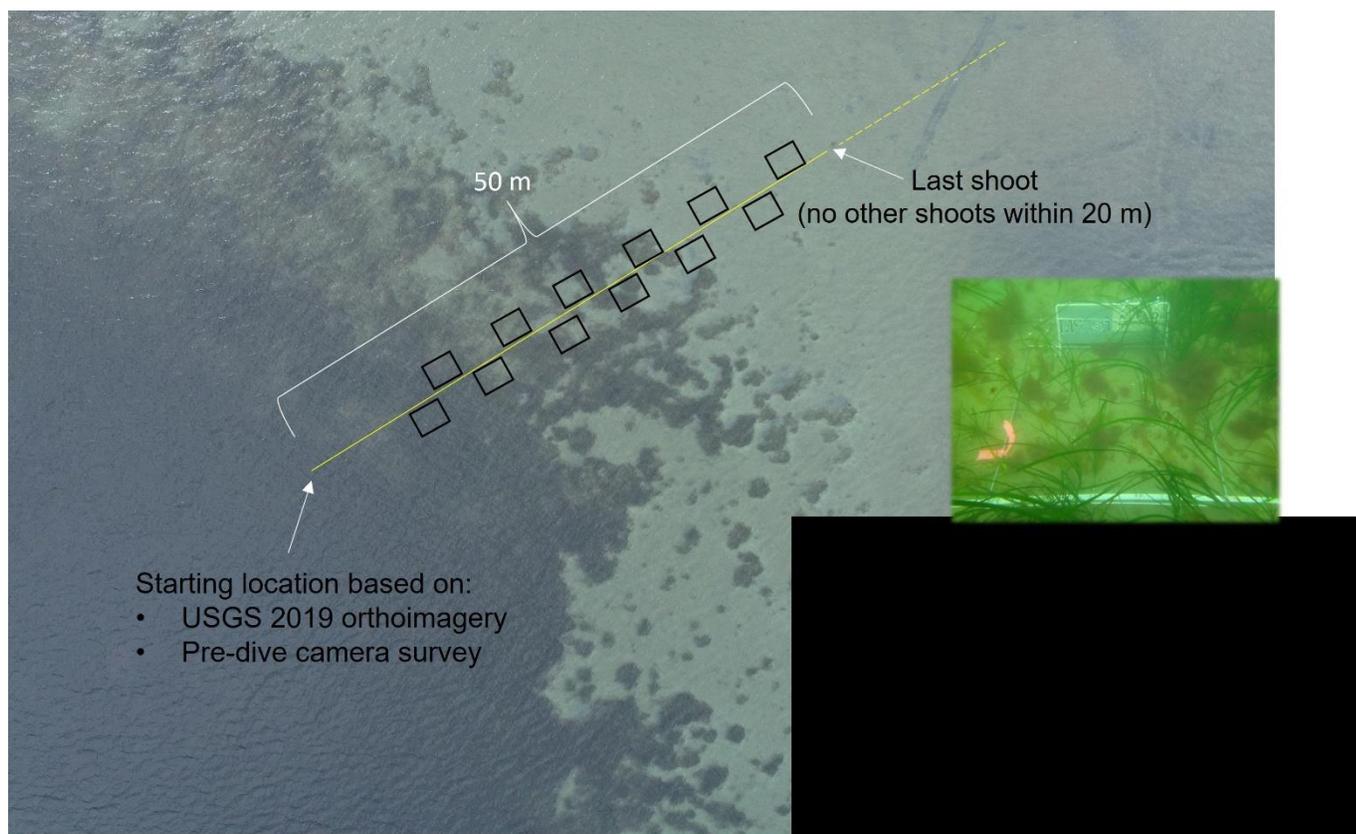


Figure 4. Example of diver transect location with 12 evenly spaced quadrat sample locations.

2.7 NON-DIRECT MEASUREMENTS

Information on tides, sun angles, weather, and precipitation will be used to decide whether to proceed with a survey within previously designated windows. After a survey, a log is created that includes exact time of data acquisition as well as weather, wind speed, wind direction, and sun angle. Verified tide heights can be

retrieved via NOAA's Boston Tide Station following the survey dates. The data sources that will provide this information are:

Predicted Tides and Observed Water Levels

Boston, MA Tide Station (ID 8443970) <https://tidesandcurrents.noaa.gov/stationhome.html?id=8443970>

NOAA redictions found [here](#). May also use Mass. Marine Trades Assoc. Page [here](#).

Sun Angle

Sun angle calculator for Boston, MA are available from: <https://gml.noaa.gov/grad/solcalc/azel.html>

Weather

Weather forecasts leading up to the planned date of imagery acquisition will be obtained from the National Weather Service for Boston. <https://forecast.weather.gov/MapClick.php?lat=42.3587&lon=-71.0567#.YYBWOWDMI2w>

3. DATA ANALYSIS

3.1 PHOTOINTERPRETATION

Imagery from each of the four remote survey types will be interpreted for eelgrass via a Heads-Up delineation approach conducted by trained partners from MITSG, NEU MSC, SSCW, and NSRWA. The use of trained partners in photointerpretation will maximize consistency of data interpretation for each method while reducing interpretation bias and increasing technical capacity among partners. The Heads-Up process is so named because the focus of the mapper is up on the screen as they digitally trace features on a map or image. The process can be performed at many scales, from source scale (e.g., 2.5 cm for drone imagery) up to a coarser harbor-wide scale.

Photointerpretation will be done in ArcGIS Pro or ArcGIS Online. At least two interpreters from each partner organization will be trained for their assigned survey method and together they will manually draw a digital polygon around visible eelgrass in imagery derived from that survey method for each of the five sites, as described further below. Each partner organization will be dedicated to only one survey method. Photo-interpreters will view the remote imagery on their screen within ArcGIS, and will draw a polygon along the outermost visible eelgrass edge while following the photointerpretation rules for that method (Table 11). The mapping exercise will target the outer boundary (edge) of the meadow only and will not delineate bare patches or other features inside the interior of the meadow. When delineating eelgrass edge, interpreters are not expected to trace every undulation, and will instead bridge patches and edge areas together that are less than 10 m apart (Fig 5), which results in some degree of line smoothing. Overall, the interpretation process is expected to result in one polygon per site. Specifications about each interpreter's computer monitor model, size and screen resolution will be recorded on the Photointerpretation processing log (Appendix F).

Table 11. Rules for photointerpretation by method

	Satellite	Airplane	Drone	Side Scan Sonar
Interpreter team	NEU MSC	NSRWA	MITSG	SSCW
On-screen spatial scale restrictions for image exploration	none	none	none	none
On-screen spatial scale restrictions for drawing eelgrass polygon	1:1000	1:1000	1:500	1:500
Spectral restrictions for image exploration	none	none	none	none
Spectral settings for drawing eelgrass polygons	Natural Color, but stretches can be applied	Natural Color, but stretches can be applied	Natural Color, but stretches can be applied	Black and white
Minimum mapping unit (for inclusion/exclusion of patches)	None – include all visible	None – include all visible	None – include all visible	None – include all visible
Maximum distance threshold (between patches, to be bridged together along the edge boundary) <i>i.e., line smoothing</i>	10 m	10 m	10 m	10 m

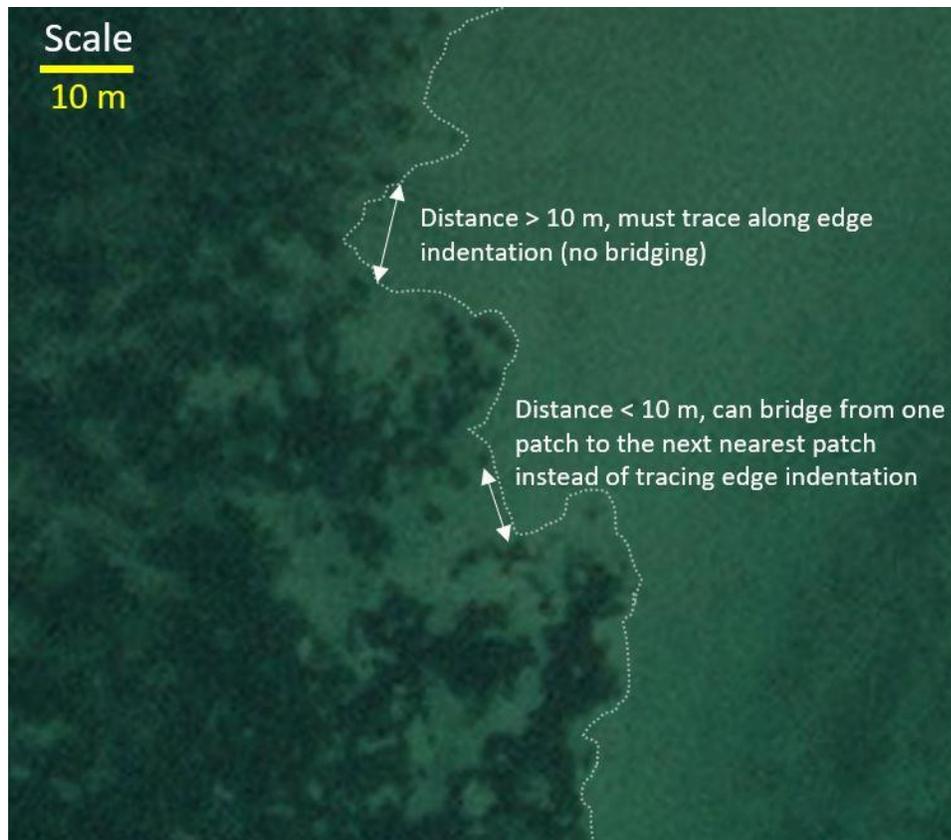


Figure 5. Example of the application of the Minimum Distance Threshold when determining how much line smoothing should be applied along edge indentations. When the distance between visible patches is < 10 m, the patches can be bridged at their closest location.

We recognize that human interpretation of imagery is a subjective endeavor that we hope to mitigate with ample quality control and training. At each partner organization, two interpreters will each independently trace eelgrass boundaries visible in the imagery, each generating an eelgrass polygon. The two interpreters will then work together to overlay their polygons and evaluate agreement between them. Where there is disagreement, the two will work together to revise the polygon, which may involve selecting one interpreter's line placement over the other's, or splitting the difference between the two. This will result in a new, final polygon that will be used in analysis. Problematic areas will be flagged with a point file for PI review.

Training will take place within 2-4 weeks of the start of photo-interpretation work, and will include the following topics and exercises:

- Overview of concepts of image resolution, accuracy, horizontal error, projections, datums, image quality, and photointerpretation considerations (tone, color, contrast, texture, shadows, shape etc.)
- Overview of the survey method used in the field
- Overview of ArcGIS tools and processes for creating new polygons
- Rules to follow during interpretation (Table 11)
- Demonstrations of different interpretation scenarios
- Supervised practice using examples, with evaluation of performance

Training records and performance of interpreters will be documented in the Training Log (Appendix F).

3.2 ASSESSING PHOTOINTERPRETATION RESULTS AGAINST DIVER AND GROUNDTRUTHING DATA

After delineations are complete and quality-assured, the diver transect data and photo-groundtruthing data will be compared to the eelgrass polygons derived from the remote sensing imagery. The difference between the diver-measured edge location (location of last shoot) and the photo-interpreted edge for each method will be the *edge detection error* (e) for that method as measured along the same bearing as the diver transect (i.e., perpendicular to the shoreline). Across all transects and sites, each remote survey method will have 15 associated e measurements. The mean error (\bar{e}) will be calculated for each survey method. If \bar{e} is smaller than the horizontal accuracy of any of the contributing datasets (e.g., the boat's GPS accuracy, ~3 m) then \bar{e} is not meaningful and the edges cannot be considered different. However, if \bar{e} is smaller than the horizontal accuracy of contributing datasets, it will translate directly into management buffers that can be applied to eelgrass maps from each method, where the use of the buffer provides more inclusive representation, and ultimately better protection, of low-density edge areas. Further, by establishing buffers we would create a process by which eelgrass maps generated from different survey techniques could be better integrated.

The groundtruthing data will be used as accuracy assessment points to evaluate the performance of each method in terms of how often it correctly detected eelgrass presence, and in terms of what levels of eelgrass coverage (% cover) were detectable using the method. All groundtruthing locations for all study sites will be grouped ($n=450$), and the *presence detection error* (p) will be established for each survey method, where:

$$p = \frac{\text{\# Assessment Points with eelgrass present within method's eelgrass delineation}}{\text{Total \# Assessment Points with eelgrass present}} \times 100$$

and the *coverage detection error* (c) will be established for each survey method and each percent cover bin, for example in the 11-20% bin, where:

$$c(11-20\%) = \frac{\text{\# Assessment Points w/ eelgrass present at 11-20\% cover within method's eelgrass delineation}}{\text{Total \# Assessment Points with eelgrass present at 11-20\% cover}} \times 100$$

This process will allow for methods to be quantitatively ranked by their ability to detect eelgrass presence as well as eelgrass presence at given coverages.

Distribution Type and Canopy Height data from the diver survey will help provide qualitative context for eelgrass detectability in the remote imagery. At each quadrat location along a transect, divers will assess how continuous, transitional, or patchy the meadow is in that location, in addition to % Cover, Canopy Height and other measurements (Table 10). While Distribution Type and Canopy Height observations won't be connected to discrete points on the map that can be spatially analyzed, their relative location along the transect can be informative. For example, if we find that eelgrass is present at high % cover and is "continuous" at one end of the transect, and is present at high % cover but patchy at the opposite end, and the remote imagery loses the ability to detect eelgrass somewhere in between, we can be confident that the eelgrass distribution played a key role in that method's success. The same can be said for Canopy Height data. These parameters will be considered on a transect-by-transect basis, and if any overarching patterns are observed they will be reported.

4. QUALITY CONTROL

4.1 SAMPLE HANDLING AND CUSTODY

This study will not result in the collection of field samples. Digital imagery, data sheets and field logs will be provided to MassBays by the project partners within 2 weeks of collection.

4.2 INSTRUMENT/EQUIPMENT TESTING, INSPECTION, MAINTENANCE

Equipment used for each survey will be inspected prior to deployment to ensure proper operation. Dive gear, drop cameras, side scan sonar and GPS units will be inspected, charged, maintained and cleaned before each field day.

4.3 ASSESSMENTS AND RESPONSE ACTIONS

The Field and Data Manager will be in frequent communication with partners during the project and will ensure that protocols from the QAPP are being following. At a minimum, the following checks will be conducted while the project is proceeding:

- Conference with survey teams before flight windows
- Attend at least 1 day of each field survey where relevant (diver, sonar, drone and groundtruthing) to ensure compliance with QAPP
- Conference with survey teams periodically during field surveys
- Review of field logs submitted after field work
- Review final imagery and imagery metadata provided by survey teams
- Initiate appropriate response actions after each check, if needed
- Report project status to Project Administrator and co-PI
- Assess DQIs as the survey progresses and deliverables become available for review

4.5 REPORTS TO MANAGEMENT

Status updates will be made throughout the project progress to the Project Administrator as well as to the MA CZM Director. Upon completion, the final report, including findings and recommendations, will be circulated broadly to the project's Advisory Committee, relevant state agencies, and the general public. Additional outreach to regulators, resource managers, other CZMs and NEPs, municipalities and consultants will be conducted to share findings.

All reports will be coordinated by the Field and Data Manager and will receive final sign off by the Project Administrator.

4.6 DATA REVIEW, VERIFICATION AND VALIDATION

The Data Quality Reviewer will be responsible for assessing that the data quality objectives have been met by reviewing QC information, including metadata files from the survey crews, image processing logs from the photointerpretation groups, and status reports. The Data Quality Reviewer will evaluate

if there have been any deviations from the QAPP and if the data quality objectives have been met, and will bring any concerns to the Field and Data Manager, who will make final decisions regarding the usability of the data. The project's Advisory Committee may also be consulted to guide data usability.

Results that are qualified may still be used if the limitations of the data are clearly reported. The decision-making process will be:

1. The Data Quality Reviewer will review data with respect to sampling design, completing the Data Quality Review Form for each data type (Appendix F).
2. If the data quality objectives are met, then the user requirements have been met and the imagery, transect data and eelgrass maps can be used without qualification.
3. If the data quality objectives have not been met, the Data Quality Reviewer will consult with the Field and Data Manager, and other project partners as needed, to make a recommendation about whether the imagery and/or eelgrass maps are still usable for their intended purpose or whether the data need to be qualified or rejected. The Field and Data Manager may initiate appropriate corrective actions to improve the quality of the data, such as additional training and re-do of photo interpretation work. Any corrective actions will be documented.
4. QA/QC will be discussed in the final report. Any QA/QC concerns and data qualifications will be noted, if needed.

A realistic example of using this decision-making process is in the case of drone imagery, which is known to be challenging to mosaic along the deep edge if environmental conditions at the time of image collection are not optimal, as described earlier. If drone imagery is not successfully mosaicked along the deep edge at one of the five sites, for example, the drone dataset for that site and for that survey method is deemed incomplete and the completeness criterion has not been met. Still, the successful portions of the drone dataset will likely still be usable (assuming other data quality criteria are met) and valuable in the analysis process. The Data Quality Review Form will guide the Data Quality Reviewer and the Field and Data Manager in evaluating any appropriate data qualifications, corrective actions, and ultimately the data usability.

5. DATA MANAGEMENT

Data will be stored and backed-up on a secure Commonwealth of Massachusetts server, with additional back-up to a dedicated project hard drive. Data will be made accessible to project partners and steering committee members during the field season for review, and to the general public when imagery and analysis datasets are finalized. Datasets are considered finalized when they have been thoroughly quality controlled and contain the appropriate corresponding metadata.

Individuals who will handle the data include the Field and Data Manager, the Data Quality Reviewer and imagery interpreters (trained partners). Data contributors and partners will be appropriately credited in metadata and reporting, and datasets will be licensed for public use. For specific data handling plans for each data type, refer to Appendix G.

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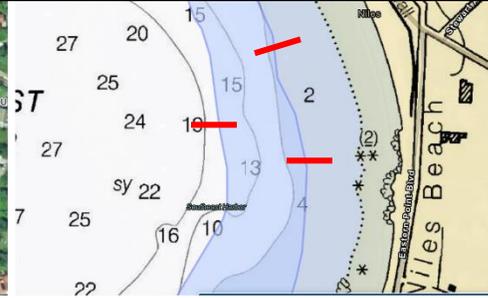
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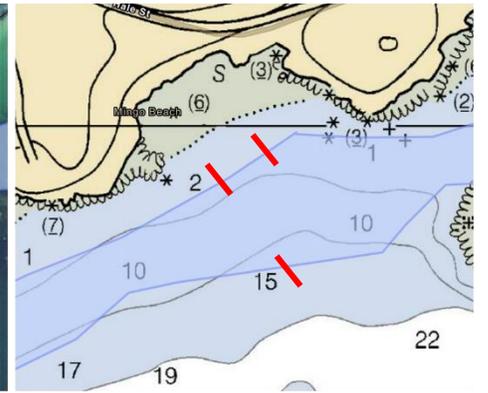
APPENDIX B. SITE MAPS

Maps showing NAIP aerial imagery (left) and NOAA nautical chart (right) for each site. The most recent DEP eelgrass map polygon is shown in blue or orange. Red lines demonstrate possible diver transect locations.

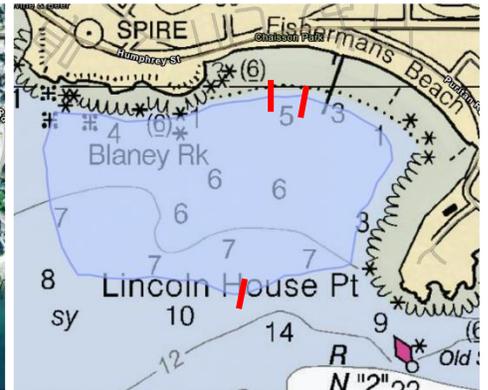
Niles Beach, Gloucester



Mingo Beach, Beverly



Swampscott Harbor



Dorothy Cove, Nahant



Cohasset Harbor



APPENDIX C. DEP EELGRASS MAPPING PROJECT STANDARD
OPERATING PROCEDURE



Commonwealth of Massachusetts
Executive Office of Energy & Environmental Affairs

Department of Environmental Protection

Eelgrass Mapping Project

Standard Operating Procedures



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MassDEP Wetlands Program

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Terminology¹:

Aerial Imagery: photographs taken by aircraft of terrestrial and aquatic features using special cameras and/or sensors designed to capture high resolution photographs and record the location of each photograph.

Algae: a simple nonflowering plant of a large group that includes the seaweeds and many single-celled forms. Algae contain chlorophyll but lack true stems, roots, leaves, and vascular tissue.

Benthic Habitat: the habitat on the bottom of a body of water such as the seafloor.

Coordinate System: is a mathematical grid that is used as a reference framework to define the positions of points on the landscape. It allows a user to identify and refer to specific locations. Latitude and longitude are the examples of coordinate system.

Datum: the reference specifications of a coordinate system. The datum establishes the benchmark for the application of the coordinate system.

Depth Finder: a device that uses reflected pulses of sound energy to measure depth.

Leveling Rod: is a graduated wooden or aluminum rod used to measure height or depth. A leveling rod is analogous to a yard stick, only a leveling rod is typically much longer.

Embayment: a recess in the coastline or an indentation of a shoreline with a direct connection to the ocean. It is typically surrounded by land on three sides, with the fourth side exposed to the ocean via an inlet, channel, or open water. Cove, bay, or lagoon is synonymous with embayment.

Emergent Plants: erect rooted herbaceous vegetation, excluding mosses, lichens and algae, which grow along or within bodies of water, with leaves or stems that extend to or above the surface of the water.

Epiphytes: in the marine environment, epiphytes are sessile organisms that grow on plants yet get their nutrients from the surrounding water. There are numerous groups of organisms that are classified as epiphytes, however algae are the most common group in the marine ecosystem.

¹ The definitions used in this document are derived from definitions provided in ESRI's GIS Glossary of Terms, and NOAA's Shoreline glossary of terms (note bibliography for hyperlinks). This glossary of terms is intended to clarify the meaning of terms as used in this manual. They do not represent legal or jurisdictional definitions.

GIS: a Geographic Information System is a software system used for creating and evaluating geographic information such as maps, aerial photographs, or site specific data.

Intertidal: the area of the seashore that is covered (underwater) during high tide and uncovered (exposed) during low tide.

Macroalgae: algae that is large enough to be seen with the naked eye. All seaweeds in the Massachusetts coastal environment are macroalgae.

Metadata: information that describes the content, origin, and attributes of map data.

Minimum Mapping Unit: the smallest contiguous area of the feature that will be mapped.

Photointerpreter: a person trained in the techniques of examining aerial photographs or other remote sensing images in order to identify the features reflected in that image.

Polygon: a fully enclosed shape on a map which distinguishes between the area inside the shape and the area outside of the shape. A polygon may be circular, rectangular, or irregular in shape.

Signature: the identification of a feature in aerial photographs requires visual evaluation of the fundamental elements of the feature on the image. Those elements are: tone, color, contrast, texture, pattern, shape, context and location. The combination of all the elements is referred to as the “signature”.

Source Imagery: as used in this document, source imagery is the aerial images captured for the specific purpose of mapping eelgrass and meets the specifications in the Image Acquisition section of this document.

Submerged Aquatic Vegetation: are vascular plants that live and grow completely underwater, or that have leaves or stems that grow just up to the water surface.

Substrate: the physical substance or layer that underlies something, i.e. sand may be the substrate that occurs on the bottom of the ocean.

Subtidal: the area of the benthic environment which lies below the level of mean low water. It is normally covered by water at all tidal stages.

Thematic Accuracy: is how well the mapped features correspond to what is actually on the ground.

Wrack: free floating mats of broken off pieces of macroalgae and/or eelgrass are referred to as wrack. Eelgrass leaves deteriorate with age and eventually break off from the shoot as new

leaves develop. In addition, algae can break from the supporting substrate and become free floating. Eelgrass leaves or free-floating algae are carried by waves, currents, and wind. It often forms mats in the nearshore subtidal area or washes up on adjacent beaches during high tides.

1.0 Introduction:

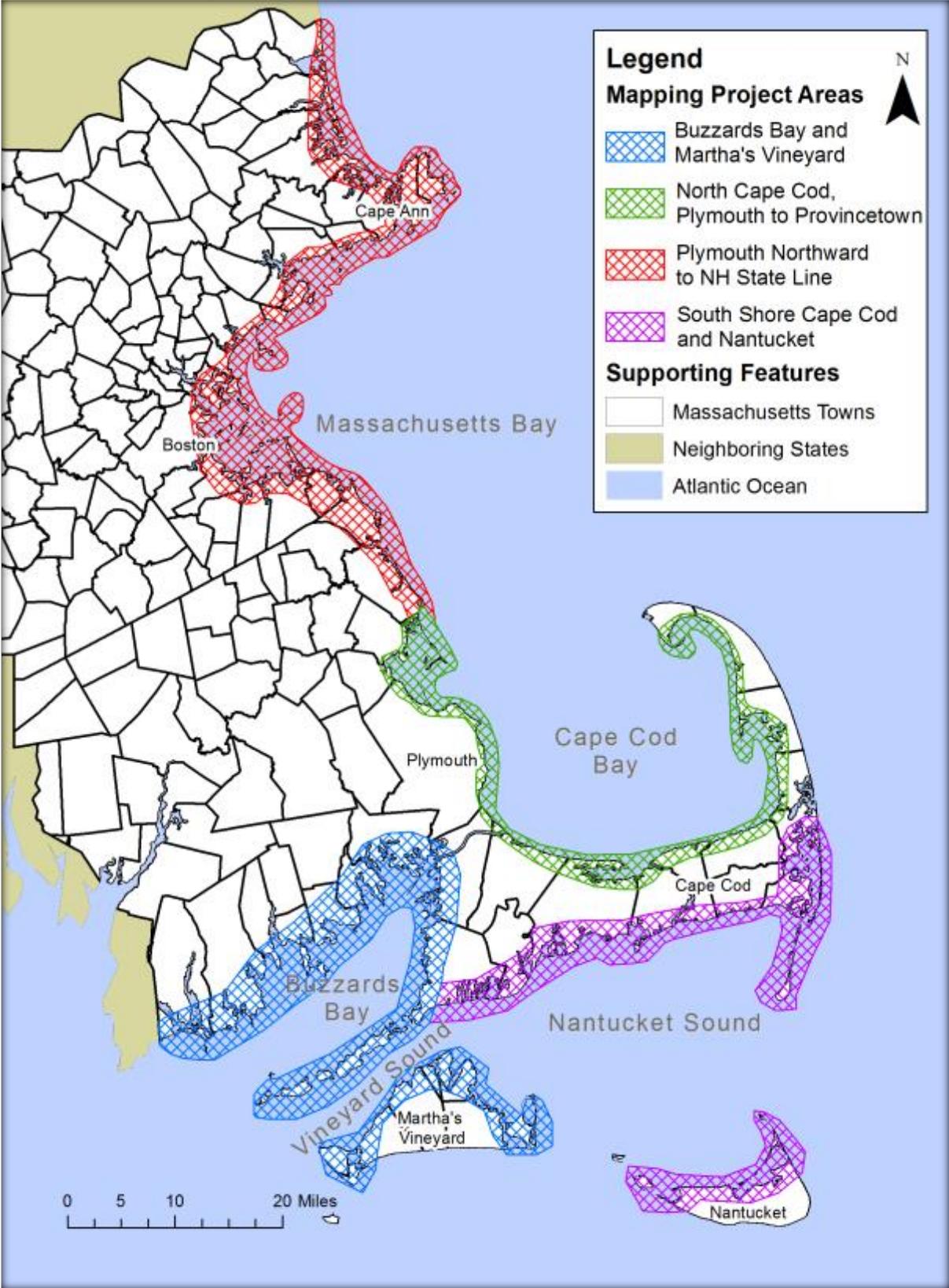
Eelgrass, *Zostera marina*, is the most common seagrass present on the Massachusetts coastline. Eelgrass beds are critical components of shallow marine ecosystems along the Massachusetts coastline. They provide food and cover for a great variety of commercially and recreationally important fauna and their prey. The leaf canopy calms the water, filters suspended matter and together with extensive roots and rhizomes, stabilizes sediment. In addition, the condition of eelgrass beds is a core indicator of water quality. Eelgrass is sensitive to degraded water quality and the loss of eelgrass beds has been linked to eutrophication resulting from excessive contributions of nitrogen from coastal watersheds. Therefore, the change in the extent and distribution of eelgrass over time is an important indicator of environmental condition used by MassDEP.

Eelgrass is a vascular plant and is often referred to as "Submerged Aquatic Vegetation"(SAV). This distinguishes it from algae, which is not a vascular plant and from the emergent saltwater plants found in salt marshes (e.g. *Spartina* spp.).

The MassDEP Eelgrass Mapping Project applies remote sensing using aerial imagery to map the extent of eelgrass beds along targeted embayments of the Massachusetts coastline. The remote sensing data is supplemented by "boat based" field verification using an underwater camera to verify benthic habitat signatures. The final product is a map of eelgrass location and extent that allows for the assessment of status and trends of eelgrass beds.

Since 1995, The MassDEP Eelgrass Mapping Project has conducted ongoing surveys of eelgrass extent in targeted embayments along the Massachusetts coastline. The initial survey conducted by MassDEP included the entire coastline of Massachusetts, but subsequent surveys are focused on selected embayments where eelgrass is known to currently or previously exist. The selected embayments are located in these project areas: Buzzards Bay and Martha's Vineyard; South Shore of Cape Cod and Nantucket; North Cape Cod, Plymouth to Provincetown; and Plymouth northward to the New Hampshire (NH) state line (*Figure 1*).

Figure 1: MassDEP Eelgrass Mapping Project Areas



2.0 Aerial Image Acquisition:

MassDEP contracts a flight over the study area to capture aerial imagery. The selected contractor is responsible for providing the following deliverables for the project:

- Aerial images suitable for benthic habitat mapping.
- Ortho-rectify 4-band image sets to achieve +/- 3m spatial accuracy.
- Generate image mosaic tiles for each project area.
- A mission log for each study area describing start and stop times for the mission.
- A Federal Geographic Data Committee (FGDC) compliant metadata record for the aerial imagery.

The contractor must document all data and data products according to Federal Executive Order 12906. All data and data products, metadata records which detail image sources, dates, datum, projections, resampling algorithms, processing steps, field records, and any other pertinent information. The metadata records conform to the Content Standards for Digital Geospatial Metadata (CSDGM) (FGDC-STD-001-1998) as published on May 1, 2000., by the Federal Geographic Data Committee (FGDC) or to any format that supersedes it as determined by the FGDC. Profiles and extensions to the standards that have been endorsed by the FGDC are used if they are applicable to data or data products. The metadata records contain any and all elements including those that are considered optional, wherever applicable to the data or data product. The metadata record contains sufficient detail to ensure the data or data product can be fully understood for future use and for posterity. The metadata records are free of errors in both content and format as determined by the metadata parser (mp) program developed by Peter Schweitzer of USGS or an equivalent. The Contractor derived metadata records are subject to review and approval of MassDEP.

MassDEP sets specifications for the image acquisitions and image processing. The delivered imagery must meet the following environmental conditions and imagery specifications to facilitate development of accurate and detailed benthic habitat data.

2.1 Environmental Conditions

Season: Preferred conditions for aerial flyovers are during May and/or June when tidal conditions and sun angle are consistent with specifications, and when eelgrass which may have been dormant during the winter months is in leaf out condition.

- Turbidity: imagery must be acquired when turbidity is low, i.e. not immediately following heavy rains or persistent strong winds, in order to provide a clear view underwater.

- Tidal Stage: Imagery must be collected within 2 hours before and 2 hours after low tide. If possible, imagery acquisitions during extreme low tide cycles are preferred. Low tide provides a better view of the benthic environment.
- Wind and Surface Waves: No wind or waves is optimal. Low wind (under 10 mph) is acceptable. Wave conditions prevent visualization of the benthic features (e.g. light reflecting off the surface of the water is not acceptable).
- Sun Angle: A sun angle above 30° is best. Sun angles above 50° are unacceptable. Glare from sunlight reflecting off the surface of the water prevents visualization of the benthic features.
- Clouds and Haze: Clouds, cloud shadows and haze all hinder or obstruct the ability to distinguish benthic habitats. Excessive clouds, cloud shadows, and/or haze shall preclude image acquisition. Cloud and shadow above 10% of the project area may be rejected as unacceptable imagery.

2.2 Imagery Specifications

- The spatial resolution (pixel size) of the imagery must be 0.25 x 0.25-meter. 0.25 meter resolution means that each pixel on the image represents 0.25 meters on the ground.
- The horizontal spatial accuracy of the imagery must be within +/- 3 meter CE95 of the position on the ground. 3 Meter horizontal spatial accuracy means that when the image is displayed in a geographic information system a point on the image is within 3 meters of the actual location of the that same point on the ground.
- The radiometric resolution of all image composites shall be 8-bit. If imagery with higher dynamic range is available, an additional set of imagery with higher radiometric resolution must be made available. The radiometric resolution of an imaging system describes its ability to discriminate very slight differences in energy (i.e. light). Imagery with a higher dynamic range is better for detecting small or subtle differences in discernable features.
- The imagery must be processed to remove atmospheric effects such as haze and to highlight the spectral response of submerged areas. All image processing or enhancements shall be fully described and included in the image metadata.
- The imagery must have minimal exposure variation between adjacent flight lines.
- Individual image frames shall be mosaicked to cover each project area.
- Imagery must be developed in Mass State Plane Coordinate System projection using the NAD1983 datum. The units must be in meters. This coordinate system and map datum is consistent with map standards set by the Massachusetts Bureau of Geographic Information (<https://www.mass.gov/orgs/massgis-bureau-of-geographic-information>)

- Spatial offsets between any band or between either the CIR or RGB composites shall not exceed 1 pixel.
- The imagery must be in GeoTiff format to facilitate analysis in a variety of software environments. A GeoTiff is a digital image with a coordinate system and map datum embedded into the aerial photograph so that when the image is displayed in geographic information system software it displays in the correct location on the landscape.
- Each image must be accompanied by an ESRI compatible pyramid layer or reduced resolution file, typically an .aux file. This allows for quicker display of large image files in a GIS.
- The naming convention for delivered mosaics shall be by project area name. If DOQQ-Q tiling is required to avoid excessive file sizes, then the DOQQ-Qs must be named following the USGS-Quadrangle-quarter-quarter convention (ex.Cape_Cod_SE-SW). Digital orthophoto quadrangle quadrats (DOQQ) tiles are mosaics of individual photographs.

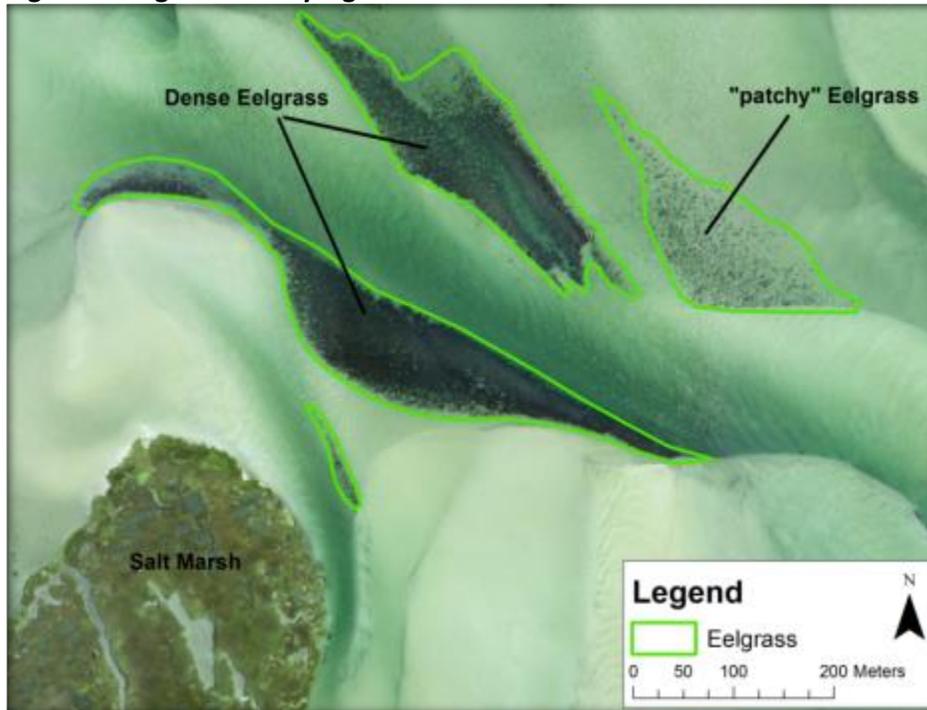
3.0 Photointerpretation and Image Analysis:

The identification of eelgrass in aerial photographs requires visual evaluation of the fundamental elements of image interpretation. Those elements are: tone, color, contrast, texture, pattern, shape, context and location. The combination of all the elements is referred to as the “signature”. Individual aerial photograph signatures can vary based on the environmental conditions under which they were captured and as a result of the image processing required for each photograph. While generalities can be made about typical eelgrass signatures, the specific signature of eelgrass resources can vary in ways that are difficult to model or consistently apply. In order to identify eelgrass resources, a human photointerpreter should have a firm understanding of eelgrass ecology and experience at field verification of various signatures in order to deduce which represent eelgrass resources.

3.1 Eelgrass Signature

Eelgrass typically occurs in protected or sheltered embayments or nearshore environments that are not subject to steady and significant current or wave action. It typically occurs in subtidal waters less than 20 feet deep. The signature is typically dark black, brown or occasionally reddish brown. Since eelgrass typically grows in sandy or other fine sediments, it often stands in strong contrast to the substrate. It typically has a rough texture, which is a result of the many leaves associated with each individual eelgrass shoot. Eelgrass resources may be very dense, but they often have a somewhat blotchy, or mottled, appearance due to bare patches within the eelgrass bed or at the outer edges.

Figure 2: Eelgrass Density Signatures



Eelgrass beds may consist of dense vegetation or they may be sparsely vegetated (referred to "patchy").

Figure 3: Eelgrass Signature



A strong eelgrass signature is typically dark black with a strong contrast and rough texture. Eelgrass beds are typically densest in the middle then become diffused at one edge of the bed and sparser ("blotchy") at the outermost edge. Eelgrass is typically found in sheltered locations that are not subject to steady and significant current or wave action.

3.2 Algae Signature

Many species of macroalgae also occur in the subtidal benthic environment in Massachusetts. Algae can generally be lumped into three groups: brown algae (Phaeophyta), red algae (Rhodophyta), and green algae (Chlorophyta). Common species include: dead-man’s fingers (*Codium fragile*), sea lettuce (*Ulva lactuca*), knotted wrack (*Ascophyllum nodosum*), and *Sargassum* (*Sargassum* spp.). Algae can occur in either protected or unprotected marine environments and ranges from intertidal rocks to subtidal areas well over 20 feet deep. This depth differential is important, because in Massachusetts eelgrass is always subtidal (rather than intertidal) and generally will not grow in waters greater than 20 feet deep. Algae often grow on rocks or coarse-grained sediment, so its contrast with the substrate is generally less pronounced than that of eelgrass. Algae signature is typically dark bluish, occasionally brownish, but generally not dark black. The texture is generally smooth (as opposed to the rougher texture of eelgrass) and it typically lacks the blotching or mottling associated with eelgrass. The outward extent of algae beds often exhibits extending “fingers” and the outward edge itself is often abrupt or distinct (i.e. rather than getting less dense over space as eelgrass often does, it just stops entirely at a certain point).

Figure 4: Example of Macroalgae



Macroalgae occurs throughout the Massachusetts coastline. Macroalgae are an important part of the coastal ecosystem, providing food and habitat for a variety of species. However, when overly abundant, they can be indicators of degraded water quality. Some are native species and some are non-native species.

3.3 Aquaculture Signature

Aquaculture is the rearing of aquatic animals or plants for food. In Massachusetts, the most prevalent form of aquaculture in the coastal environment is the rearing of shellfish, primarily oysters and clams. Shellfish are often raised in what is essentially a series of trays placed in shallow subtidal waters. At first glance, the photographic signature resulting from aquaculture has a similar appearance to eelgrass. It is generally dark brown or black and has a somewhat rough texture and a blotchy or patchy appearance. However, the edges of aquaculture are generally abrupt and distinct as opposed to the diffuse edges in eelgrass beds. In addition, because aquaculture is anthropogenic it is generally square, rectangular, or round in overall shape. It is this anthropogenic shape that distinguishes aquaculture from eelgrass beds.

Figure 5: Example of Aquaculture



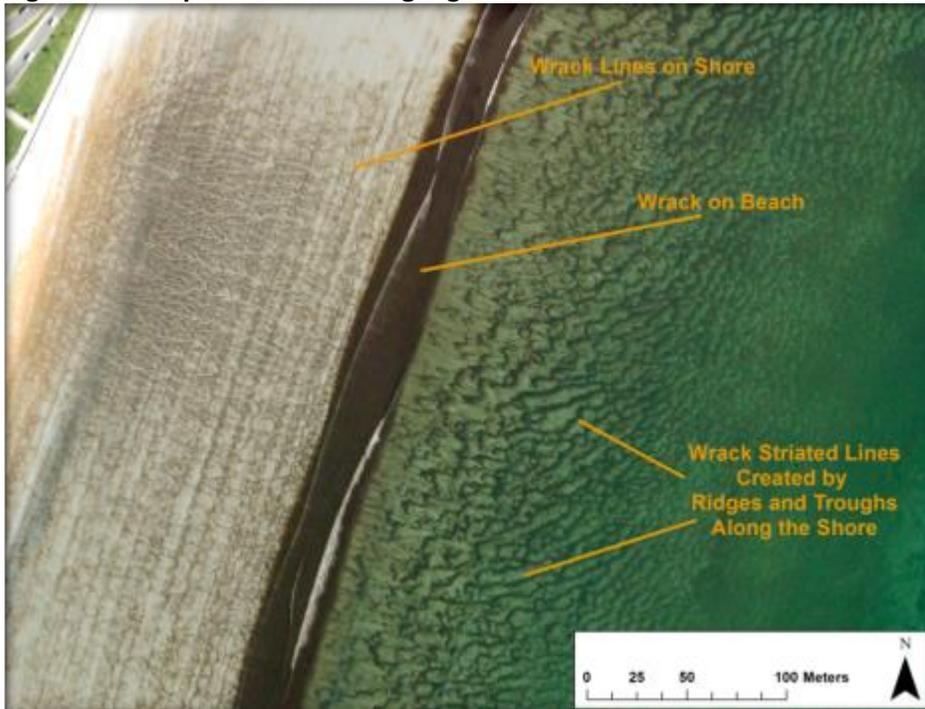
The output of the shellfish aquaculture industry in Massachusetts was valued at approximately \$25.4 million in 2013 which in turn generated approximately \$45.5 million in the Massachusetts economy (<https://www.mass.gov/service-details/aquaculture>).

3.4 Wrack Signature

Eelgrass leaves deteriorate with age and eventually break-off from the shoot as new leaves develop. In addition, algae can break off from its supporting substrate and become free floating. Free floating mats of detritus or algae are referred to as wrack. Wrack is pushed by wind and wave action and is often deposited in shallow water at the upper end of protected coves. In very shallow water wrack creates a dark brown signature with a smooth texture, whereas it has a rougher texture when on an exposed beach. In shallow water, wrack has a dark

striated appearance that is caused by the action of the tide creating ridges and troughs in the substrate of very shallow water nearshore and the wrack gets trapped in the troughs. The dark striated line signature helps to identify free floating wrack from rooted vegetation. Lines of wrack, deposited by the most recent high tide, can also sometimes be observed on shore. Those wrack lines are generally parallel to the trend of the beach. While wrack may consist of eelgrass blades, the present of wrack does not indicate that eelgrass is present nearby. Due to currents and wind, wrack material can travel great distances across coves or embayments so any potential eelgrass bed adjacent to wrack material must exhibit an eelgrass signature independent of the wrack material before it can be identified as an eelgrass bed.

Figure 6: Example of Free Floating Algae Wrack



Wrack deposits on the shore provide a place where sand can collect and provides nutrients that support shore vegetation thereby helping to build and protect the beach and dunes. It also provides a habitat where shore birds can forage for food. However, excessive accumulations of wrack can cause management problems for the maintenance of recreational beaches.

4.0 Procedure for Selecting Areas for Field Data Collection:

While the MassDEP eelgrass map data is developed via remote sensing of aerial photography, extensive field work is conducted to ensure the accuracy of those eelgrass delineations. Field verification entails documenting the presence/absence of eelgrass at selected points, referred to as “Sample Points”, within the project area as well as documenting other benthic features. Between 1000 and 1600 Sample Points are anticipated for verification each season. Each Sample Point has a question for the field team to read and should be answered in the comment

field of the “Field Point” (See Section 5.0 Field Data Collection). The following are examples of reasons the photointerpreter would create the Sample Points:

4.1 Apparent Change Since Last Survey

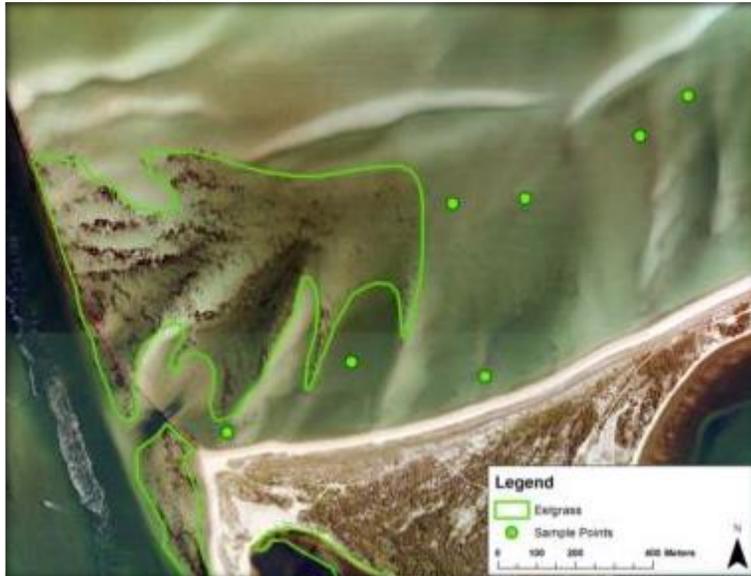
Sample Points are established if a review of past aerial imagery and previous delineations indicate that a significant change may have occurred. That change may be eelgrass expansion or eelgrass loss. In either event, Sample Points are created in order to document the potential change.

Figure 7: Eelgrass Bed Before Loss



In this 2013 aerial photograph an eelgrass is readily visible and extends essentially east to west.

Figure 8: Eelgrass Bed After Loss



In this 2015 aerial photograph of the same area the eelgrass bed appears much smaller in size. The western side of the polygon is greatly reduced. Sample Points are created in order to direct the Field team to verify that Eelgrass is no longer present.

Figure 9: Eelgrass Bed Before Gain



In this example, an aerial image from 2002 exhibits the distinct signature of an eelgrass bed and was mapped as such. The eelgrass bed does not extend to the southeast.

Figure 10: Eelgrass Bed After Gain



In 2013, the eelgrass bed appears to have extended to the Southeast. In this case Sample Points are placed with in the area of potential expansion in order to confirm the increase in eelgrass extent.

4.2 Outer Edges

Much of the Massachusetts nearshore environment has a sandy substrate which provides a useful color contrast to the darker eelgrass signature; however, the deeper the water the harder it is to discern that signature. Therefore, the outer edge of an eelgrass bed can be the most difficult to identify. When an eelgrass signature is identified in shallow nearshore water, but the outer edge is not readily apparent, Sample Points are created to locate that outer edge.

Figure 11: Outer Edges



At the outer edges, eelgrass vegetation can get sparse, the benthic substrate may change, and the deeper the water the harder it is to discern features. Therefore, field work is often focused on verifying that outermost edge.

In Figure 11, an eelgrass signature is readily apparent in the nearshore waters, however as the water gets deeper offshore, the signature blends in with the darker color of the deeper water. Locating the outer edge is one example of why it's important for the field team to read and answer the questions that accompany the Sample Points. A question in a Sample Point may specifically ask the Field team to locate the outer the edge rather than simply documenting one point. If the outer edge is farther out from shore, the field team must first capture a Field Point at the location of the initial Sample Point and enter all relevant data including a comment such as, "No, edge is farther from shore." Second, the field team must then navigate away from shore until they find the edge. After finding the edge a second field point should be captured that includes all relevant data such as, but not limited to, documenting that the point is at the outer edge of the eelgrass bed.

4.3 Difficult to Discern Areas

Eelgrass can have a distinct signature, but there are many environmental conditions that can confound it. Algae can grow in, on, or amongst the eelgrass, thus obscuring the eelgrass signature. Cobble piles, dredge spoils, or artificial material can create a false "blotchy" appearance similar to that of eelgrass. Natural sediment laden water in estuaries with large freshwater inputs can obscure the water column making it difficult to recognize any discernable

feature. Sample Points are created in order to confirm the source of the signature in areas where that signature is inconclusive.

Figure 12: Eelgrass Bed Difficult to Discern



In this example, a wrack signature can be seen near shore. There are also large rocks present, however that is more indicative of the presence of algae. Further off shore, a darker, stain-like signature, is present. It is not clear what that darker color is. In this situation field investigation is conducted throughout the area in question to determine what the features in question are.

4.4 Signature Confirmation

Aerial photointerpretation is based on human evaluation of an aerial photograph to identify features. That evaluation involves assessing the signature of the feature. Because eelgrass signatures can vary depending on water depth, clarity, and processing of the digital imagery, Sample Points for the field team to verify are sometimes placed within areas that the photointerpreter already believes to be eelgrass in order to confirm that signature. The information returned by the field team informs the photointerpreter about the presence and density of eelgrass at that point. This assists the photointerpreter delineate the eelgrass bed in questions and also provides the photointerpreter with confidence about the features being identified. That confidence leads to better judgment on the part of the photointerpreter and improves overall accuracy and consistency in the mapping.

Figure 13: Eelgrass Signature that Requires Confirmation



This area exhibits a “soft” eelgrass signature, by confirming that areas believed to be eelgrass actually are eelgrass, the photointerpreters gain confidence in their mapping decisions. Such signature confirmation is an integral part of any successful photointerpretation project.

5.0 Field Data Collection:

Once Sample Points are created by the photointerpreters they are uploaded to ERSI ArcGIS Online (AGOL). From AGOL both the photointerpreters and field team can access the data and view edits in real-time, which allows for seamless sharing of data between the photointerpreters and the field team. The field team accesses the data using Arc Collector, which is a mobile GIS application used for field data collection. Sample Points are immediately available for the field team in Arc Collector once they are uploaded to AGOL. Once field data is collected it is automatically saved to AGOL if there is a data connection. If the field team is out of data range, Arc Collector saves the data on the field tablet, and it is later synchronized online once the field team is within data coverage range. Once the data is synchronized to ArcGIS online it is fully visible and available to the photointerpreters. The data is retrieved via AGOL and incorporated into the photointerpreter mapping project.

The quality control procedure for assessing the field data collected at each of the points is conducted by the photointerpreters. This procedure involves a series of queries of the tabular data and documenting consistency with signature determination. MassDEP will be present during field collection during the start of the field season, and periodically throughout the season, to ensure that field methodologies are appropriately and consistently applied by the field team.

An example of inconsistent tabular data would be a data point stating that eelgrass is “true” (present), but the density is recorded as “none.” If eelgrass is present, then there should be percentage of density recorded in the data. An example of inconsistency with signature documentation is when the aerial image clearly shows a feature of some sort present, yet the data point documents no benthic features and the comment field does not provide further explanation. The list of data queries of the tabular data used for QC purposes is attached as *Appendix A*.

Each Field Point collected by the field team must have a picture attached that is representative of the benthic environment. This picture is reviewed to ensure that it is consistent with the tabular data collected.

Data that contains inconsistencies will be reviewed with the field team. Discrepancies that cannot be resolved means the data will not be used for documenting field conditions. Only points that have passed the quality control process are incorporated into the mapping project.

The field work requires a research vessel, high definition underwater camera, navigation chart plotter, laptop/tablet with an operating system that is compatible with ERSI ArcGIS/Collector,

and an external Differential Global Positioning System (DGPS) that has greater than one-meter accuracy. Utilizing the field equipment listed above, the field team navigates to the Sample Points identified by photointerpreters during the desktop analysis, and documents the benthic habitat features by creating and populating a new field point. It is important to note that the Sample Point and Field Point are not the same data points. The Sample Points are created by the photointerpreters to direct the field team to a location to investigate and give them specific instruction on the information the photointerpreter needs (e.g. “Is this the outer edge”). A Field Point is then captured by the field team to document site features and record the exact location where the field data was collected. The following attributes are recorded at each field point:

Date and Time: the date and time the field point was collected is auto populated during the creation of the field point in the file geodatabase.

Point type: there are two different *point types* that can be selected from the dropdown list for this field, “PI” meaning photointerpreted and “QC” meaning quality control. Photointerpreted pertains to data gathered for the purposes of documenting the benthic feature in order to inform the photointerpreter. Quality control pertains to data gathered for the purposes of documenting quality assurance of the delineated eelgrass beds and is discussed further in the *Map Data Validation* section of this SOP.

Location: where the field team is in reference to the eelgrass bed. This field is populated by selecting the corresponding *location* from a dropdown list: inner, middle, outer, or other. *Inner* refers to the innermost edge (closest to shore) of the eelgrass bed; *middle* refers to a point within the eelgrass bed; and *outer* refers to the outer most edge (the most seaward) of the eelgrass bed. If *other* is selected, a comment describing the point type is documented in the *Observations* field.

Zostera: eelgrass is documented by viewing real-time footage from the underwater camera and determining if eelgrass is present or absent. From the dropdown list, the field team selects either “true” if eelgrass is present or “false” if eelgrass is absence.

Zostera density: the eelgrass density is documented by viewing real-time footage from the underwater camera, using best professional judgment, and selecting the corresponding density range from the dropdown list in the field. When present, eelgrass density is differentiated into five (5) cover ranges: <5%, 5%-25%, 26%-50%, 51%-75%, and 76%-100%. Appendix B provides a percent cover chart. Below are examples of eelgrass percent cover.

Percent Cover of Zostera (Density)

<5% Cover



5-25% Cover



26-50% Cover



50-75% Cover



76-100% Cover



Macroalgae: algae are documented by viewing real-time footage from the underwater camera, using best professional judgment, and selecting from the dropdown list either “true” if present or “false” if absent.

Macroalgae Density: algae density is documented by viewing real-time footage from the underwater camera, using best professional judgment, and selecting the corresponding density range from the dropdown list in the field. Macroalgae density is differentiated by the following cover classes: <5%, 5%-25%, 26%-50%, 51%-75%, and 76%-100%. Macroalgae density is determined using the same method shown in *Percent Cover of Zostera*.

Macroalgae Type: the type(s) of algae present is documented by viewing real-time footage from the underwater camera, using best professional judgment, and selecting the macroalgae type using the dropdown list in that field. The options are: None, *Codium*, Green Filamentous, Red Filamentous, *Ulva*, *Sargassum*, Mixed Algae Types, Undetermined, or Other (explain).

Macroalgae Comments: the different type(s) should be recorded in this comment field if *Other* is selected from the *Macroalgae Type* dropdown list.

Codium sp.



Green filamentous



Sargassum sp



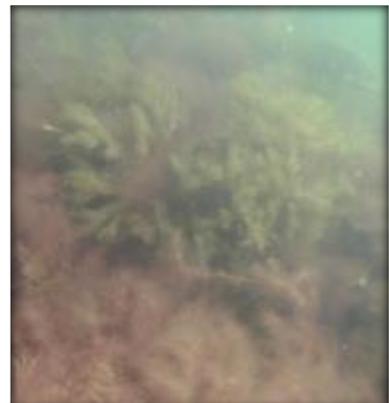
Red filamentous



Ulva



Mixed Algae types



Epiphyte Density: the presence of epiphytes on the eelgrass is documented by viewing real-time footage from the underwater camera, using best professional judgment, and selecting the corresponding density range from the dropdown list in the field. Epiphyte density is differentiated by the following cover classes: <5%, 5%-25%, 26%-50%, 51%-75%, and 76%-100%.

< 5%



5-25%



26-50%



51-75%



76-100%



Substrate: the type of substrate present is documented using the dropdown list in that field. The options are: Sand, Silt/Clay, Pebble/Cobble, or Shellbed. The substrate type is determined by viewing real-time footage from the underwater camera, using best professional judgment.

Sand



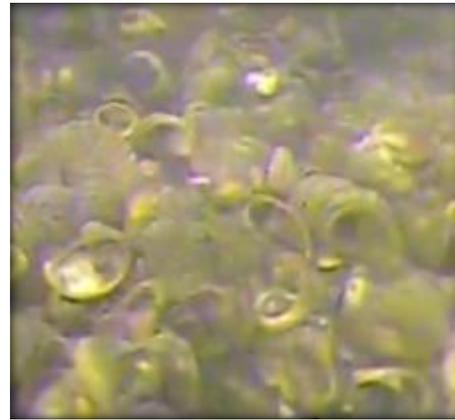
Silt/Clay



Pebble/Cobble



Shellbed



Depth of Water: a measurement to the ocean floor. This measurement is determined via the on-boat depth finder, or in the case of very shallow water, a leveling rod. The depth is manually entered into the designated field. The unit is measured in meters and is recorded to one decimal place (tenths of meters).

Observations: a blank text field allowing for the recording of any relevant observations that are not documented in any of the other data collection fields.

Photo: The underwater camera takes a still photograph in a jpeg format of the benthic habitat at the field data point. That photo is embedded into the attributes of the Field Point.

Once data is collected it is automatically saved to ArcGIS Online if there is a data connection. The data can then be downloaded from ArcGIS Online and incorporated into the photointerpreter mapping project.

6.0 Creating and Editing Eelgrass Polygons:

6.1 Mapping Project Areas

Prior to starting the delineation of the eelgrass resources, the specific boundaries of the given project area and embayments where mapping will occur will be defined and the area to be mapped will be given a name based on its geographic location (e.g. South Cape or Boston Harbor). That boundary will be determined by using the source imagery to identify areas where mapping will occur. Project area mapping boundaries will be created by a simple polygon created in an ArcGIS environment. Only areas that are covered by the source imagery will be mapped. Areas that are outside of the defined mapping project areas are presumed to not be reviewed or included as part of that defined mapping project area. Note that areas that are outside of one defined mapping project area may be included in another defined Project area, but each mapping project area will have specific boundaries that identify when and where mapping occurred within it. Any area outside of any defined mapping project area is presumed to not have been reviewed (unless it is identified in another project area).

6.2 Eelgrass delineation

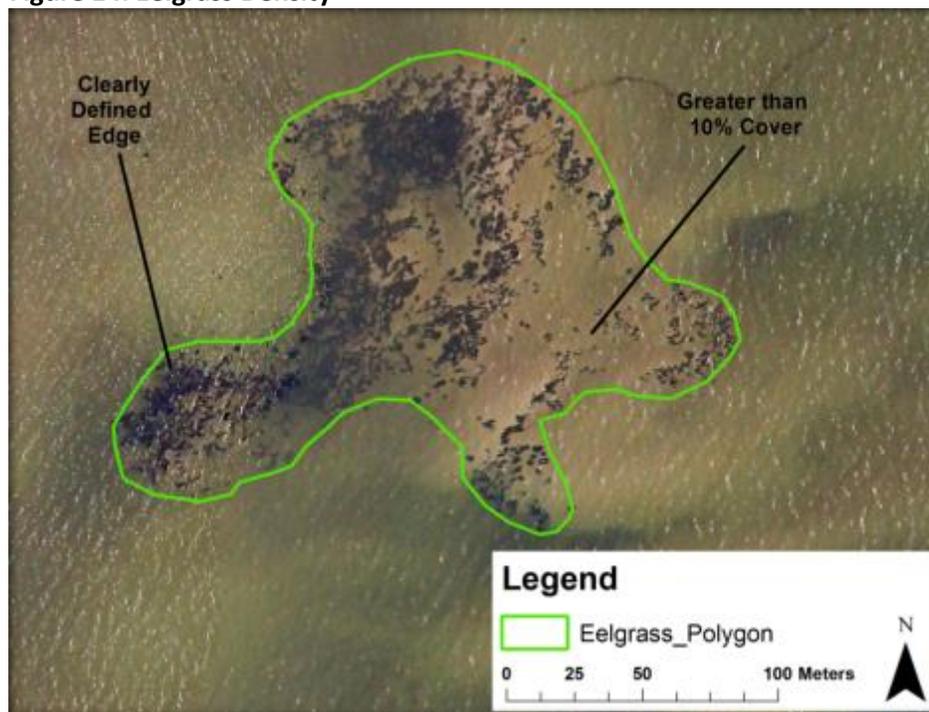
The source imagery will prevail as the data source for mapping. Field data collected in accordance with this manual will serve to inform the photointerpreter what the various photo signatures indicate. Field data will be incorporated into the mapping as completely and accurately as possible. Although the information obtained from the aerial photograph and subsequent field data collection serves as the primary source for delineation, the photointerpreter will make full use of as much collateral data as possible. That data may include, but is not limited to: NOAA Charts, MassGIS Ortho imagery, EagleView Imagery, GoogleEarth Imagery, Bing Imagery, site specific aerial imagery, previous MassDEP mapping, side-scan sonar mapping conducted by the Division of Marine Fisheries, benthic surveys conducted by academic researchers, and information provided by municipal officials may all be used to provide additional information. Such collateral information may suggest that a change in the size or delineated shape of a polygon is in order. Such changes will only be made if the collateral information is discernable on the source imagery and/or has been field verified. In the event that changes have taken place since the time of the photograph (due to natural or human causes), such changes will be delineated only when the area in question is clearly defined, locatable on the source imagery (i.e. spatial coordinates that allow the photointerpreter to

identify the area that has changed are provided), and the changes have been verified by field work.

6.3 Delineation

The photointerpreter will create a polygon and draw the boundary of the eelgrass at the outer edge of eelgrass bed as visible on the source imagery. The outer edge is determined by a photo-recognizable signature of eelgrass that occupies a minimum of 10% cover or where field verified information documented in accordance with this manual has identified the edge. Percent cover will be determined using the chart in *Appendix B*.

Figure 14: Eelgrass Density

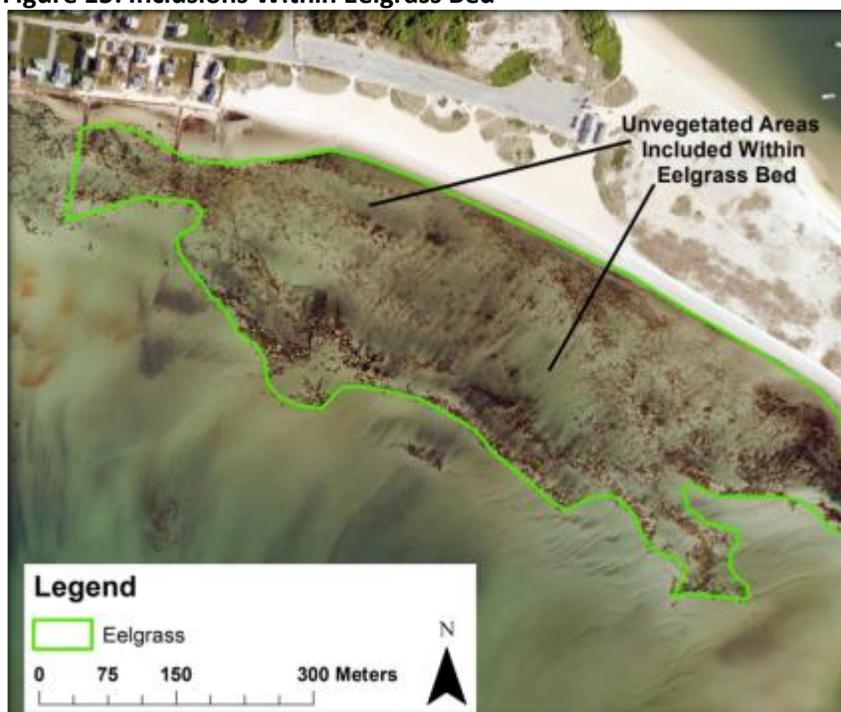


The eastern side of this polygon the eelgrass vegetation gets sparse, but the area photograph indicates that it still occupies at least 10% cover and therefore is included as part of the eelgrass bed.

The minimum mapping unit (MMU) shall be $\frac{1}{4}$ acre (1011.7 square meters). This minimum size will be used for delineating all individual eelgrass beds, and areas of non-eelgrass within beds as discussed in the following paragraphs.

While eelgrass beds can be continuous (i.e. wholly vegetated throughout the bed) it is widely recognized that eelgrass beds often contain patches of un-vegetated areas. Un-vegetated areas will be mapped as part of the eelgrass bed when: 1) the un-vegetated area is surrounded by continuous eelgrass vegetation greater than the minimum mapping unit; and 2) the un-vegetated area consists of the same substrate as that which occurs within the eelgrass bed.

Figure 15: Inclusions Within Eelgrass Bed



Unvegetated areas within eelgrass beds are a common occurrence. They are considered to be part of the eelgrass bed itself-not a separate feature.

Discontinuous areas (i.e. areas not vegetated with eelgrass) will not be included within the eelgrass polygon when they are greater than the minimum mapping unit and: 1) They consist of benthic feature other than eelgrass (i.e. algae) or 2) the substrate is of a different nature than that which occurs in the eelgrass bed (e.g. cobble strewn areas, boulders, or exposed tide flat within an eelgrass bed on a substrate of fine sand). If the edges of two eelgrass beds which meet the minimum mapping unit are separated by more than 30 meters, then they are delineated as separate eelgrass beds. Generally, those two beds would be considered a continuous bed if there was less than 30 meters separating them.

Figure 16: Intertidal Area



Eelgrass occurs in the subtidal environment. Tide flats are intertidal and as such are a different feature from an eelgrass bed. Therefore, they are excluded from the eelgrass polygon.

Eelgrass beds will be labeled as *eelgrass*. In the event Widgeon grass (*Ruppia maritima*) is encountered the same mapping conventions will apply and the polygon will be labeled as *Ruppia*. Any undelineated areas (i.e. areas not within a polygon) are presumed to be neither eelgrass nor *Ruppia*. No other features will be delineated.

7.0 Map Data Validation:

The eelgrass map data will be tested for thematic accuracy by creating randomly located quality control (QC) Sample Points within eelgrass polygons throughout the project area. Random points are used to eliminate site selection biases. The points are randomly located within the boundaries of the mapped eelgrass polygons throughout the project area using the random point generator tools in ArcGIS software. A total of 360 random points will be generated each season. Each QC point has a unique identification number ranging from 1 to 360. All QC Sample Points are a minimum of 50 meters apart. This ensures that QC points are spatially distributed so that: a) points do not fall in such close proximity to each other that they are essentially sampling the same location; and b) large polygons will be available for more QC sampling points within them than small ones, which prevents multiple sampling within just a few small polygons.

Figure 17: Data Validation Within Polygons



The data validation approach provides that all polygons are available for quality control. Small Polygons may have only one QC Sample Point, medium polygons may have several, and large polygons may have many.

The randomly generated points will be uploaded to the Collector online map. The field team will spend a minimum of four days at the end of the field season with the intent to document the presence and/or absence of eelgrass at between 280 and up to 360 QC Sample Points. Because it is understood that eelgrass bed can contain un-vegetated patches, in the event a QC point falls on such an inclusion, the field team will sample the nearest discernable feature on the image in order to ensure that the un-vegetated area is within an eelgrass bed. The field team will document the site conditions during this validation phase using the same methodology described in *Field Data Collection*, with the exception that the “Point Type” selected will be “QC” (i.e., Quality Control). In the event that the site has changed since the date of the mapping effort (e.g. due to coastal storms, dredging projects) the change will be documented in the observation section of the QC Field Point. The point will then be abandoned and the next nearest point on the list will be completed. All QC points will have a unique ID (Numbers 1-360). QC Field Point verification will be spatially distributed throughout the project area. This approach eliminates site selection bias in QC point verification.

The data validation points will be analyzed to determine the percentage of validation points that have eelgrass present at the point. The accuracy percentage will be calculated using the following formula:

Percent Accuracy = (Validation Points with Eelgrass Present/Total Random Points Tested) *(100)

Points where change occurred since the time of the mapping has been documented will not be incorporated into the thematic accuracy assessment.

8.0 Publishing Data:

After the data has been created and validated, a metadata description will be written which contains a brief description of what eelgrass is and why it is mapped; a brief explanation of the methodology; a description of the attribute fields for the map data; and information pertaining to the maintenance and availability of the data. The maps will be made available for online viewing or downloading via the Bureau of Geographic Information's (MassGIS) website (<https://www.mass.gov/orgs/massgis-bureau-of-geographic-information>). The metadata document will be provided with the map data.

9.0 Conclusion:

The MassDEP Wetlands Conservancy program has been mapping eelgrass along Massachusetts's coasts since 1995. The purpose of this manual is to document the mapping standards of the MassDEP Eelgrass Mapping Project beginning in 2019. It incorporates to the extent feasible the mapping standards used since 1995 and documents the current data collection practices. Any changes in this methodology must be fully documented in an update to this manual.

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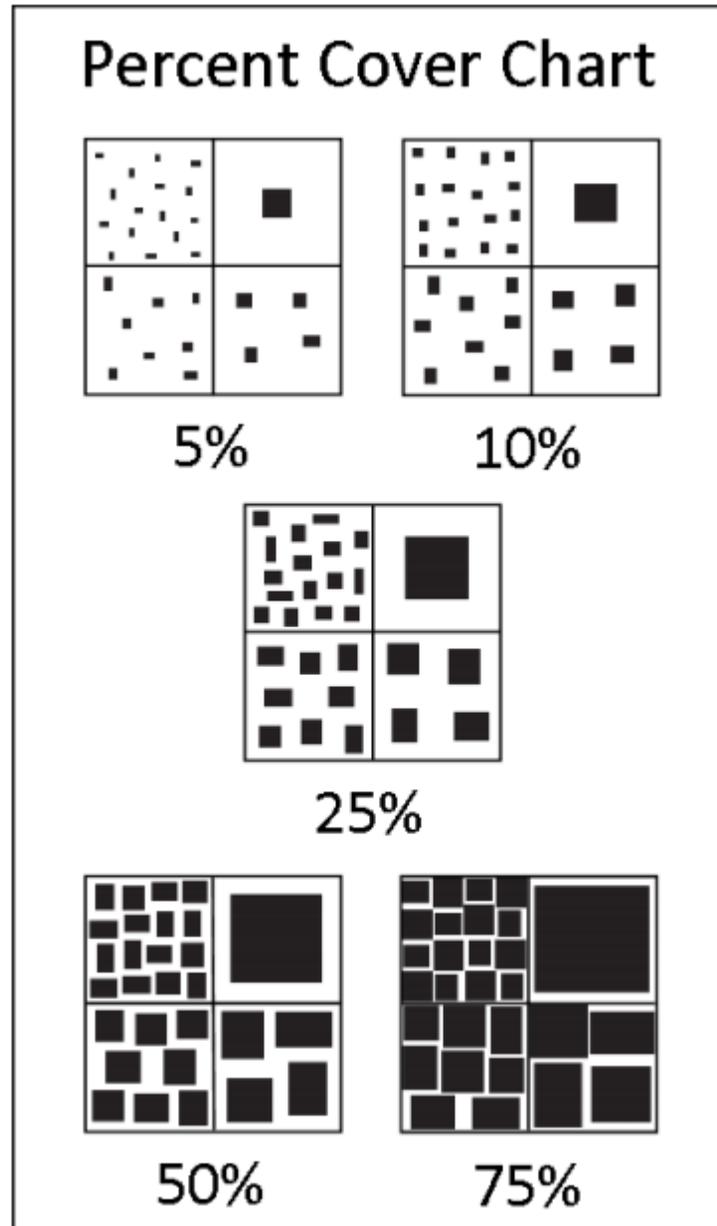
Appendix A: Quality Assurance / Quality Control GIS Queries

Each data point created must have all fields recorded, and an attribute table is created from the aggregate of all 1000-1600 data points collected throughout each season. A QA/QC on all 1000-1600 data points collected throughout the season requires a semi-automated procedure. In order to conduct this QA/QC, a series of queries have been created to confirm that the data collected is reasonably consistent, and the values do not contradict one and other. The following queries will be run on the completed attribute tables prior to using the data to inform the eelgrass polygon delineations:

1. Zostera Present is null
2. Zostera Present is equal to 0 – True **and** Zostera Density is equal to 0 - None
3. Zostera Present is equal to 0 – True **and** Zostera Density is null
4. Zostera Present is equal to 0 – True **and** Location is null **or** Location is equal to 3 - None
5. Zostera Present is equal to 1 – False **and** Zostera Density is not null
6. Zostera Present is equal to 1 – False **and** Epiphyte Density is greater 1 - < 5%
7. Zostera Present is equal to 1 – False **and** Location is equal to 0 – Outer **or** Location is equal to 1 – Middle **or** location is equal to 2 – Inner
8. Algae Type is equal to 5 – Mixed Algae Type **or** Algae Type is equal to 7 – Other (explain) **and** Algae Comment is null
9. Algae Present is equal to 0 – True **and** Algae Type is null **or** Algae Type is equal to 0 – none **or** Algae Density is equal to 0 – None **or** Algae Density is null
10. Point Type is not equal to 0 – PI **or** Zostera Present is null **or** Substrate is null **or** Depth (Meters) is null

Data that contains inconsistencies will be reviewed with the field team. Discrepancies that cannot be resolved means the data will not be used for documenting field conditions. Only points that have passed the quality control process are incorporated into the mapping project.

Appendix B: Percent Cover Chart²



² Schoeneberger, P.J., D.A. Wysocki, E.C. Benham, and Soil Survey Staff. 2012. Field book for describing and sampling soils, Version 3.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

APPENDIX D. DMF STANDARD OPERATING PROCEDURES
MANUAL FOR SIDE SCAN SONAR

**Standard Operating Procedures Manual for
Sidescan Sonar
Massachusetts Division of Marine Fisheries**



November 2016

2nd Edition

FOREWORD

The purpose of this Standard Operating Procedures (SOP) document is to provide DMF employees with consolidated and standardized guidelines and requirements for conducting, processing, and generating sidescan sonar surveys for various purposes including habitat mapping and target identification. This manual summarizes current best practices and utilizes information from other similar guidance documents including the NOAA Field Procedures Manual for hydrographic surveys (April 2010), the Recommended Operating Guidelines (ROG) for Side-scan Sonar by Mapping European Seabed Habitats (August 2005), and procedures described in the manufacturers guidelines for the equipment referenced.

CHANGE HISTORY

This document will require periodic updating. Recommended changes and other comments regarding the manual should be forwarded via email to steve.voss@state.ma.us. A summary of changes is provided below:

Date	Edition	Description of changes
11/5/2015	1	Sections for tasks anticipated in the future are included as place holders.
11/2/2016	1.1	Simplified the calibration section, added maintenance details.
12/1/2016	2.0	Added photos, updated information related to our own protocols.

1. Description of Systems

The systems utilized for sidescan survey work include the sidescan transducers and topside processing units, the GPS signal systems, and the vessels and mounting systems used on each vessel. These are described below.

1.1. Sidescan Systems

1.1.1. Klein 3000

The Klein 3000 sidescan sonar is a dual frequency single beam sonar that can simultaneously collect at 132 kHz and 445 kHz frequencies (this is commonly called a 100/500 kHz system) on both sides (two transducers). The horizontal width of the beam is 0.7° at 132 kHz and 0.21° at 445 kHz. The Klein 3000 sidescan system is owned by MIT Seagrant and is on loan to DMF. Our key points of contact at MIT Seagrant are Michael Sacarny and Chrysostomos Chrysostomidis (the Director). There is no MOU or other formal representation of our sharing relationship. The system is primarily comprised of the towfish, two tow cables (one for hand deployment, the other a winch), and the topside processing unit. The same laptop is typically used for deployments of the Klein 3000, but that laptop is also used for other activities. The winch cable is a 300m double armored steel cable (Diameter (OD): 10.2 mm/0.40 in) on a Hannay Reels Winch. The hand-reeled cable is a 75m lightweight cable (Diameter (OD): 10.3 mm/0.405 in) was used on the site selection and pilot survey. The winch cable does not require depressor weights for deeper deployments.



Towfish and hand-held cable.



Laptop and topside processing unit.

LOCATION OF ITEMS			
Building B - (Duchaine Blvd., New Bedford, MA)	QTY	DESCRIPTION	MODEL #
Loose Items	1	Klein 3000 Towfish (1,000m depth limit)	Model 3210
	1	Hannay Reels Winch (w/ slip ring) & 3,000m Cable	EPC 22-30-31-20-RT
	1	Hannay Motor (DC)2-3 hp/12V/75amp	P56- SX043
	1	Wooden Pallet (for winch)	
	DMF Purchase	1	75m Tow Cable
In Processing Box- (wooden box)	1	Processing Unit	3110
	1	Ethernet Hub	
	1	Manual	
	1	Sonar Pro Operation Manual- Chap. 3	
	1	Copy of Sonar Operation Manual- Chap. 4	
	1	Null Modem Cable	
	3	Cat-V Cables	
	1	3COM Power Adaptor US, 120V/60Hz/21watts	
	1	3COM Power Adaptor UK, 230V/50Hz/.1amp	
	5	2 AMP/ 250V Slo-Blow Fuses	BAG # 13000045
5	630 Ma/ 250V Slo-Blow Fuses	BAG # 13000043	
In ASSY, ACCESS KIT (rubber bin)	2	O-Rings, 2.984ID X 3.262OD BUNA N	BAG # 15900006
	1	Silicone Grease, DC-4	BAG # 12700418
	5	Screws, PH MS M3X5MM SS	BAG # 12500695
	2	Screws, SHCS, M8X12MM, 316	BAG # 12500876
	2	Screws, FHMS, M6X12MM, PHLPS, 316	BAG # 12500823
	1	Hex Key, "L", 2.5mm Key	BAG # 13400063
	1	Hex Key, "L", 6mm Key	BAG # 13400064
	1	Connector, Shunt .100 Gold Plated	BAG # 12900252
	10	Cable Ties, 7.5X .185 In Black	BAG # 12700510
	1	Hazard Material Literature, DC- 4 Silicone	BAG # 17500003
	1	Tow Pin, Towfish	BAG # 16200013
	1	8-Pin Dummy Plug Connector	BAG # 12900687
	2	Tail Fins	BAG # 14202028
	1	Driver, Hex 8mm	loose
	2	Pins	loose
	1	Locking Sleeve	loose
	1	8-Pin Male Cable End	loose
	2	Thin Aircraft Cables w/ Loops	loose
	1	Shackle, 5/16 in.	loose

1.1.2. Humminbird 698

The Humminbird 698CI HD SI Combo sidescan sonar has two 455-kHz, 86° transducers and an 83/200 kHz (60°/20°) dual beam downward-looking bathymetric sonar. It was purchased in spring 2015.



Humminbird 698CI HD SI Combo.

1.1.3. *Humminbird 999*

The Humminbird 999CI HD SI Combo sidescan sonar has two 455-kHz, 86° transducers and two 800-kHz, 55° transducers and an 83/200 kHz (60°/20°) dual beam downward-looking bathymetric sonar. The user must select between low (455-kHz) and high (800-kHz) resolution. It was purchased in late summer 2015.

Building B - (Duchaine Blvd., New Bedford, MA)	QTY	DESCRIPTION	MODEL #
Humminbird Sidescan	1	Full Kit	999CI HD SI
Ser.#: 14050203-0018	1	Control Head w/ cover	
	1	Head Mounting Rack	
	1	Transducer with cable	
	1	Battery cable	
	1	Mounting kit, bolts, screws	
	1	Manual	
DMF acquired seperately	1	Trolling Motor Mount	
	8	SD cards	
	1	PVC extention rod	
	1	PVC mounting piece	
	1	Mounting table	
	4	Fuses	
	1	Fuse Holder	

1.2. GPS Systems

1.2.1. *Trimble GPS*

Trimble ProXT with Tempest Antenna

1.2.2. *Garmin GPS*

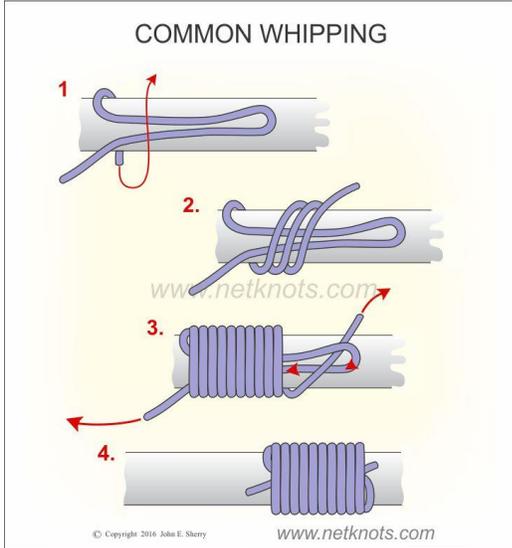
Garmin GPSmap 76 handheld with Garmin antenna

1.3. Vessels & vessel mounts

Several different vessels are used to deploy the sidescan systems, including the Mya, skiffs from 14-25 feet in length, and jet skis.

1.3.1. *Mya*

The Mya is an X foot Eastern lobster vessel. It has a draft of X and is designed for work in larger harbors, bays, and sounds. It has a pothauler and a boom which can be deployed off of either gunnel and straight astern. The Klein 3000 is optimally towed by orienting the boom straight astern, hanging the towing sheave from the boom, and securing the handheld cable with a separate line secured to the cable with a whipping knot (see Figure X) then tied to a cleat on the mast the holds the boom. This arrangement is captured in Figure X.



1.3.2. Flatfish

The Flatfish is a X foot bass boat. It is designed for shallow, calm waters. The Humminbird units can be deployed off of this boat with a trolling motor mount. They can be powered by hooking up to the boat battery but a fuse must be in line.

1.3.3. Jetski

Jetskis are designed for shallow, calm waters. The Humminbird units can be deployed off of this type of boat with a trolling motor mount. They can be powered by hooking up to the boat battery but a fuse must be in line. We found jetskis to be uncomfortable for more than a couple of hours of surveying but their rapid deployment and capability in very shallow waters can be advantageous.



1.3.4. *Maritime skiffs, privateers*

DMF skiffs tend to be roughly 17' long center consoles with engines in the 200 hp range. They typically have a draft on the order of 1.5 feet and are designed for work in small and large harbors as well as bays and sounds in calmer weather conditions. The Klein 3000 can be towed by securing the handheld cable with a separate line secured to the cable with a whipping knot (see Figure X) then tied to a cleat on the gunnel. The Humminbirds can be pole mounted using a variety of gunnel mounts. A generator is required to power the Klein 3000 and a large battery or hooking up to the vessel battery is required for the Humminbirds.





1.3.5. *Other vessels*

When a vessel is chartered for sidescan sonar surveying, the key vessel components to ensure adequate operating conditions include:

Cover. Adequate protection from the elements. The Klein requires a computer and the processing unit is not weather tight. The Humminbirds are more forgiving and can be exposed even to light rain.

GPS. A place to connect the GPS antenna and route it to the Klein processing unit. The Humminbirds will need signal access since the GPS antenna is built into the processing (head) unit.

Power. The Humminbirds can be powered off of a battery. The Klein requires 120v AC on the vessel or a generator.

Towing/mounting. How the towfish (Klein) or transducer head (Humminbird) will be towed or mounted is a critical consideration. We have built tow bars for the Klein and used a variety of gunnel mounts for the pole-mounted Humminbird transducers.

Speed. We commonly survey at 2-4 knots.

Navigation. How the vessel will navigate survey lines and have access to the sidescan view or not should be considered.



Aluminum L-bracket bar across stern of an offshore lobster vessel. Sheave is hanging from the middle of the bar. It did begin to sag, so a pipe or U or square pipe bar might have been a better choice for longer-term work.



Support bracket for bar mounted to gunnel.



Whipping knot securing blue tow cable to exhaust post on the centerline of the offshore lobster vessel.

2. Preparation & Maintenance

2.1. Calibration Requirements and Methods

2.1.1. Sidescan Sonar Systems

Sidescan sonar object detection and classification performance is largely a function of the original system specifications. The towfish pressure sensor in the Klein 3000 will be serviced and calibrated by the manufacturer whenever the horizontal positioning accuracy of side scan targets is in doubt.

The table below identifies dates of service.

Date	Description of service

2.1.1.1. Sidescan Sonar Calibration

A calibration test should be conducted at least every five years to demonstrate the system's ability to detect and accurately position seafloor targets across the system's range on both sonar channels. Test information is recorded in a Sidescan Calibration Table which is stored in the cruise report logbook. The Sidescan Calibration Test consists of a minimum of 10 side scan passes on a target approximately 1 m x 1 m x 1 m. The target is imaged from a variety of ranges and directions, with survey speed, water depth, and weather representative of typical survey conditions. A dedicated test target lobster pot with a taught buoy line can be used for this check or a site such as the Sculpin Ledge artificial reef. The absolute position of the target should be established

prior to sampling by getting a GPS fix on the buoy. Targets of opportunity, such as buoy blocks, lobster pots, and appropriately sized rocks, may be sufficient as long as a high accuracy absolute position of the target can be established for comparison with sidescan detected positions. The recommended line plan for conducting a Sidescan Calibration Test is in Figure X.

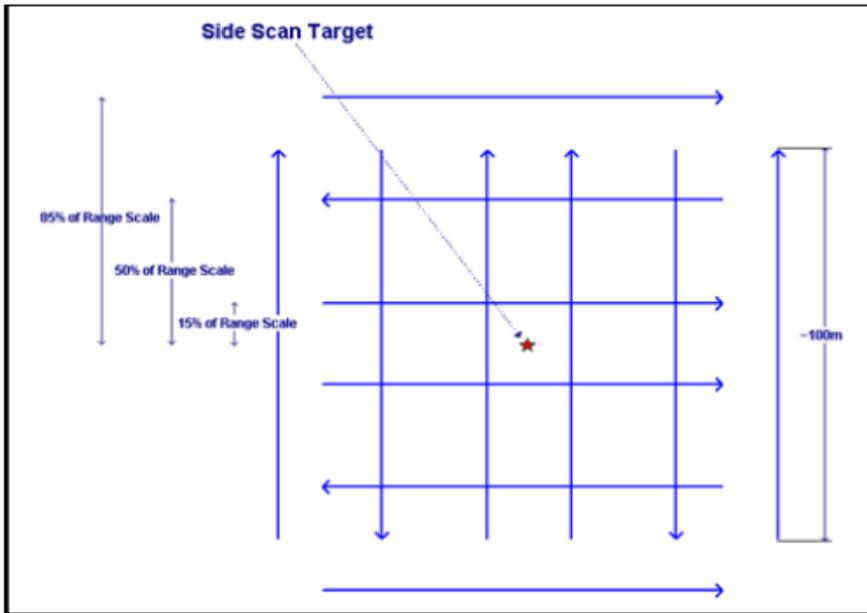


Figure 1.1. Recommended line plan for the Sidescan Calibration Test.

Test data is processed in CARIS or SonarTRX and evaluated to identify any systematic problems with the sonar or vessel offsets. If the contact is not detected in at least nine of the 10 passes, the system should be re-tested. If detection remains problematic, the system should be returned to the original equipment manufacturer for assessment.

Successful object detections will be used to compare the mean detected position with the absolute target position and to compute the approximate 95% Confidence Radius for the system. This radius should not exceed 5 meters for hull-mounted systems and 10 meters for towed systems. Several methods can be used to estimate the 95% Confidence Radius. 1) Plot the detected target positions in ArcGIS, and use the "Compute Statistics" function to compute the sample standard deviation of the x and y components of the detection positions (computing statistics of the Eastings and Northings yields values in meters). 2) Enter the x and y coordinates in two columns in Excel. Calculate the standard deviation(σ) of each. Use the following formula to calculate the 95% Confidence Radius: $95\% \text{ confidence radius} \approx \sqrt{(\sigma_x^2 + \sigma_y^2)}$

Assuming a normal distribution, 95% of the samples will fall within 1.96 standard deviations of the mean. If the distribution of detections is similar in x and y, the 95% Confidence Radius is roughly 1.96 times the square root of the sum of the squares of the standard deviation of detected positions in x and y. If the distributions in x and y are not similar, it is likely that a systematic bias exists that was not canceled by ensonifying the target from multiple ranges and directions. 3) Measuring the error for each detection (the distance from the absolute target position to the detected position) and compute the sample mean and standard deviation of the errors. The approximate 95% Confidence Radius is then the sample mean plus 1.96 times the standard deviation.

2.1.1.2. *Periodic Quality Assurance*

Before surveying with the Klein 3000 system, a “rub test” should be performed to confirm that the whole system (towfish and topside unit) is operational prior to deployment. For the rub test the operator or an assistant physically rubs one transducer on the towfish and then the other while the system is pinging. A return on the corresponding channel of the imagery should be visible. A rub test failure can indicate system errors such as incorrect gain or power settings, a faulty cable, or damaged transducers. This test should be conducted while the towfish is out of the water and dry, to avoid the possibility of electric shock. This check should be annotated on the field set-up sheet.

The rub test is not required prior to surveying with the Humminbird transducers since they are simple to remove from the water and assess if there is no signal once surveying has begun.

Caution: Do not leave the Klein 3000 towfish turned on or the Humminbird transducers pinging for more than 3 minutes while out of the water. These systems are cooled by being in the water and can be damaged by excessive heat buildup if left on when not deployed.

2.1.1.3. *Offset Measurement*

The purpose of our sidescan surveys is habitat mapping and target identification (as opposed to bathymetric surveys) therefore, vessels are not surveyed for parameters such as instrument positions, waterline, or dynamic draft.

Depending upon survey goals and whether the sonar configuration is pole-mounted or towed, the need for offset measurements will vary. Whether or not an offset is necessary for a particular survey will be identified by the survey lead and indicated on the field set-up sheet. Offset requirements for each type of configuration are described below.

2.1.1.3.1. Pole-mounted configuration

The transducer is affixed to a pole which is secured to the gunnel of the vessel. The depth of the transducer below waterline will be measured with a measuring tape with the vessel not moving and the vessel as balanced as possible. In some circumstances, the GPS antenna can be placed directly above the transducer on the top of the pole and no additional measurements are needed. If the GPS antenna is offset from the pole, the X and Y offset will be measured with a measuring tape and recorded on the field sheet. All measurements shall be recorded on the field set-up sheet.

2.1.1.3.2. Towed configuration

The actual towfish position is typically calculated using the tow point, the towfish depth, and the cable out measurements. Towfish depth may be determined by a depth sensor installed in the towfish or calculated by subtracting the towfish height (determined by a separate echosounder installed in the towfish or the first return of each sonar ping) from the depth of water (determined from a vessel echosounder). Cable out can be estimated visually from calibrated markings on the cable or measured with an electronic cable counter. Cable out should be recorded in feet. All measurements shall be recorded on the field set-up sheet.

1.3.2. GPS Systems

1.3.2.1. Trimble GPS

No calibration done.

1.3.2.2. Garmin GPS

No calibration done.

2.2. Annual Maintenance

Sidescan sonar systems should undergo an annual assessment of condition, thorough cleaning, and parts inventory. This activity will typically occur in the winter. Further detail is provided in each section below.

2.2.1. Sidescan Systems

2.2.1.1. Klein 3000

Rinse instrument and cable. Check all connections, clean and apply grease as needed. Inventory parts. Reorder missing parts. Verify that all survey data is removed from hard drive. Update computer hardware and software.

2.2.1.2. *Humminbird 698*

Rinse instrument and cable. Check all connections, clean and apply grease as needed. Inventory parts. Reorder missing parts. Remove SD cards.

2.2.1.3. *Humminbird 999*

Rinse instrument and cable. Check all connections, clean and apply grease as needed. Inventory parts. Reorder missing parts. Remove SD cards.

2.2.2. GPS Systems

2.2.2.1. *Trimble GPS*

Rinse antenna and cable. Check all connections, clean and apply grease as needed. Inventory parts. Reorder missing parts.

2.2.2.2. *Garmin GPS*

Use damp cloth to wipe down instrument. Dry. Rinse antenna and antenna cable with damp cloth. Dry. Neatly coil in storage box. Check all connections, clean and apply grease as needed. Remove extra waypoints.

2.2.3. Vessels

Several different vessels are used to deploy the sidescan systems, including the Mya, skiffs from 14-25 feet in length, and jet skis. All of these vessels have routine maintenance conducted as needed.

2.3.Storage

All instrumentation is rinsed and then allowed to air dry. It is then stored in original packaging or in plastic boxes, adequately padded to protect from damage.

2.4.Software Systems

The software utilized for field collection is SonarPro for the Klein 3000 and the Humminbird proprietary software built into the Humminbird display unit. The software utilized for data viewing/replay is SonarPro for XTF and SDF files and HumViewer for DAT and XTF files. The software utilized for data processing is CARIS HIPS/SIPS and SonarTRX. The following computer and software maintenance should be conducted annually, usually in the wintertime: 1) All survey data files are backed up to storage devices in at least two locations (for example, the V drive and an external hard drive); 2) Delete all survey data files from the field/data collection system; 3) Complete any software and computer hardware upgrades.

3. Pre-Survey Planning

3.1. Crew & Vessel Safety

The number one priority is the safety of the crew and vessel. Safety shall be the foremost consideration in all aspects of sidescan sonar surveys. It is the responsibility of the field leader, as well as vessel crew, to be aware of safety hazards and take steps necessary to ensure undue risks are avoided, even if it means ceasing operations. Good planning and information can minimize risks.

Recommended practices to increase safety include, but are not limited to the following:

- Use historical weather information to prepare for seasonal patterns.
- Review the survey region for exposed areas, constricted areas, shallow areas, surf, etc.
- Plan on surveying challenging areas when weather, tides, and currents are optimal.
- Review prior survey field sheets. Often, the field sheets will describe deficiencies, hazards, and challenges from prior surveys and field experience.
- Discuss survey area with other DMF personnel familiar with the site.
- Work progressively from safe water towards unknown, shallow, or potentially hazardous areas.
- Use daily survey information progressively in the field to minimize hazards. Communicate survey and safety information to all personnel involved in operations.

3.2. Survey Planning

3.2.1. Survey Scope

Survey limits will be defined prior to conducting field work for the purpose of the field work.

3.2.2. Survey Line Planning

Survey lines will be established based on the desired amount of overlap of the sidescan data acquisition and the expected range. Typically 150% is the goal. This overlap should be achieved by running each successive line at a distance of $\frac{1}{4}$ swath width. The swath width will be determined by the range scale (swath width is 2x the range scale). The sidescan range scale is dependent on the frequency used (the resolution required) and the depth of the sonar unit. The sonar should be maintained at an altitude of 8-20% of the range scale during acquisition. If possible, sidescan data should be acquired by running lines generally parallel to depth contours to avoid imagery distortion caused by slopes in the athwartships direction. Line plans should be created in SonarPro or on the Humminbird chartplotters. On vessels where the vessel chartplotter is being used for navigation, the line plan can be generated on the vessel chartplotter. Line plans should account for changeable field conditions; several line plans with varying direction should be developed prior to the start of data acquisition. It is typically preferable to head into and with the wind rather than have effects from cross-winds. If time allows, this can be done once on site when field conditions can be fully assessed. When the survey area is particularly small, running lines by site using the onboard chartplotter is acceptable.

The length of the lines will be calculated and used, along with the estimated survey speed (usually 4 knots), to estimate the number of field days needed to cover the survey scope. Estimations should include buffer to allow for transit to and from the site and turns.

3.2.3. Preparing the Survey Crew

At least two survey crew should conduct data acquisition. Survey crew should be identified and given a pre-cruise briefing that covers the following topics:

- Meeting location and time
- Vessel logistics (which vessel, who is driving)
- Survey location
- Expected length of the survey day
- Need for special equipment and food
- Basic overview of the plan for the day (meeting, loading, transiting and trailering boat to the field location, preparing boat and equipment, transit to survey location, survey logistics/expectations, type of data being collected, etc)
- Contact information in the event survey is cancelled due to weather

3.2.4. Preparing equipment

It is good practice to ensure all equipment is working a day or two ahead of the survey date. If equipment hasn't been used for an entire season, more time ahead of the survey should be planned to test equipment and ensure that everything is operable. Once tested, all gear should be packed carefully to ensure safety during transit to the field site. Being prepared in the field is crucial to ensure maximum efficiency. A standard gear checklist for sidescan surveys is shown in Figure X. Additional equipment or redundancy may be necessary to accommodate unusual conditions or multiple day surveys. The necessary storage media should be identified and packed. The file location on disk shall be identified on the field log sheet. A basic toolbox should be assembled and packed.

4. Data Acquisition

4.1. Sonar Imagery Acquisition

4.1.1. Klein 3000, Sonar Pro

4.1.1.1. *System Setup*

4.1.1.2. *Recording Data*

4.1.2. Humminbird

4.1.2.1. *System Setup*

4.1.2.2. *Recording Data*

4.2. Groundtruthing

Ideally all sidescan sonar surveys are followed by underwater camera surveys to verify the presence and interpretation of the patterns recorded in the acoustic imagery. The underwater camera surveys should occur as soon as possible after the sidescan sonar surveys. If done on the same day, a grid pattern of stations is recommended to record seafloor imagery. An alternative method is to process the sidescan imagery into a mosaic, identify the boundaries of various seafloor hardness/roughness patterns, and then plan video stations representative of each pattern type. Towed video can be used to help confirm the location of boundaries identified in the sidescan sonar imagery.

Video methods should follow protocols in the Standard Operating Procedures Manual for Underwater Video for the Massachusetts Division of Marine Fisheries.

4.3. Sensor Risk Management

4.3.1. **Best practices for preventing loss of equipment**

A fail safe line shall be attached to the gunnel mount or the tow cable.

4.3.2. **Best practices for recovery of lost equipment**

If the sonar transducer is lost, the Man Overboard button on the vessel-mounted GPS system should be activated. This will place a waypoint on the GPS screen which can be used to set up a search and rescue pattern. The onboard depth/fish finder should be used to scan the area in a pattern near the area of loss. If a target is identified, it should be marked as a waypoint on the GPS unit. Since our surveys typically occur in water shallower than 100 feet, recovery can be achieved by any safe method to do so (e.g. snorkeling or scuba diving). If this is insufficient or impractical, grappling with a grappling hook is recommended.

5. Data Processing and Analysis

5.1.Data Processing Workflow

5.1.1. CARIS

5.1.1.1. Creating HIPS Vessel Files

5.1.1.2. Creating CARIS Projects

5.1.2. SonarTRX Pro

SonarTRX Pro has relatively sophisticated capabilities in an inexpensive and easy to learn software package. The main limitations of this program are that it can only process one line at a time, it cannot mosaic multiple lines together, and the correction algorithms can only assume a flat seafloor. Although this is somewhat inefficient, the program produces high quality results with minimal user input making it simple to use. It can also produce X, Y, Z data, but we do not typically use it for that so those instructions are not provided. For further help and questions, SonarTRX hosts a yahoo user group and more information can be found at <http://www.sonartrx.com/web/Home/Support>. There are also online video tutorials at <http://www.sonartrx.com/web/Home/Tutorials>. The Customer Service email is support@SonarTRX.com and the Customer Service phone number is 808-383-3007. The User Manual is on the office server at \Habitat Project\Habitat Research\EQUIPMENT\SonarTRX.

- Open SonarTRX Pro
- On the Main Menu, click on Import

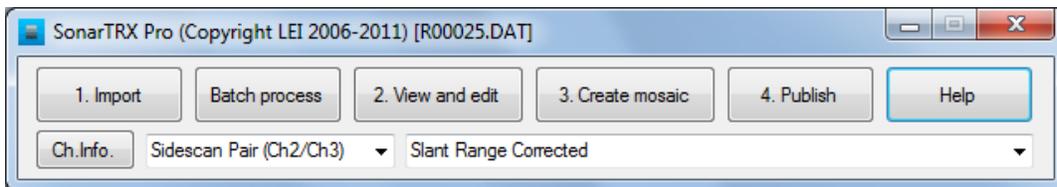


Figure 4-1. SonarTRX Pro Main Menu

- Select input file
- Select General Options as identified in Figure 4-2.

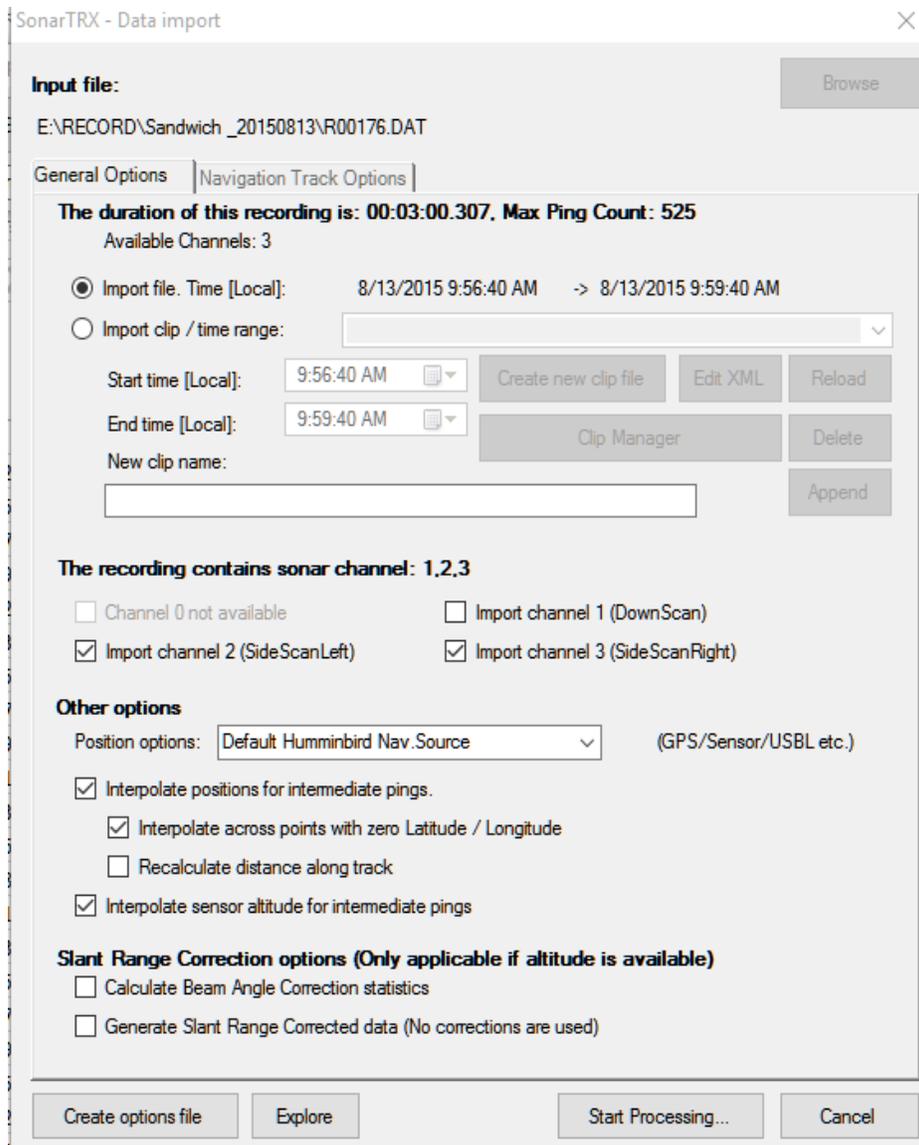


Figure 4-2. Data import selection for SonarTRX.

- Click on Start Processing then Close
- On the Main Menu, select View and Edit
- Look at navigation tab (the first tab to open) to verify line looks correct
- Select SRC/TVG tab.
- Click Calculate Histogram button.
- Conduct SRC/TVG correction.

SRC stands for Slant Range Correction and TVG stands for Time Varying Gain. A slant range distortion is an across-track distortion caused by the sidescan angle; near-range areas are more compressed in space than far-range areas. Slant range correction is a geometric correction which remaps the pixels from their apparent position to the true one, and is computed from the

elapsed receiving time and the sonar platform’s height (from page 65 of The Handbook of Sidescan Sonar by Philippe Blondel, Springer, 2009). Slant range correction is dependent on the altitude, so water column removal is typically done at the same time as SRC. The water column as automatically identified by SonarTRX is typically used, but if it is poorly recognized by the automatic algorithm, or if there is a data or visual quality need, the water column can be re-delineated by the sonar analyst.

Time-varying gain refers to the backscatter decreasing with increasing range; the same object at a further range from the sonar will have less backscatter than the same object closer to the sonar (from page 64 of The Handbook of Sidescan Sonar by Philippe Blondel, Springer, 2009). Most sonars have TVG amplifiers in the towfish that correct for this error. In post processing, additional gain corrections can be made to minimize gain changes that went uncorrected in data collection or still remain.

The Beam Angle Correction tool is a radiometric correction tool that accounts for the loss of resolution due to the increased beam footprint at further ranges. For our purposes, we use the automatic Beam Angle Correction (BAC). Our experience has shown that using default altitude and BAC corrections have been sufficient for our needs. However, specific projects may require manually defined altitudes or more sophisticated BAC. For those needs, refer to the SonarTRX user manual. For standard surveys, use settings indicated in Figure 4-3.

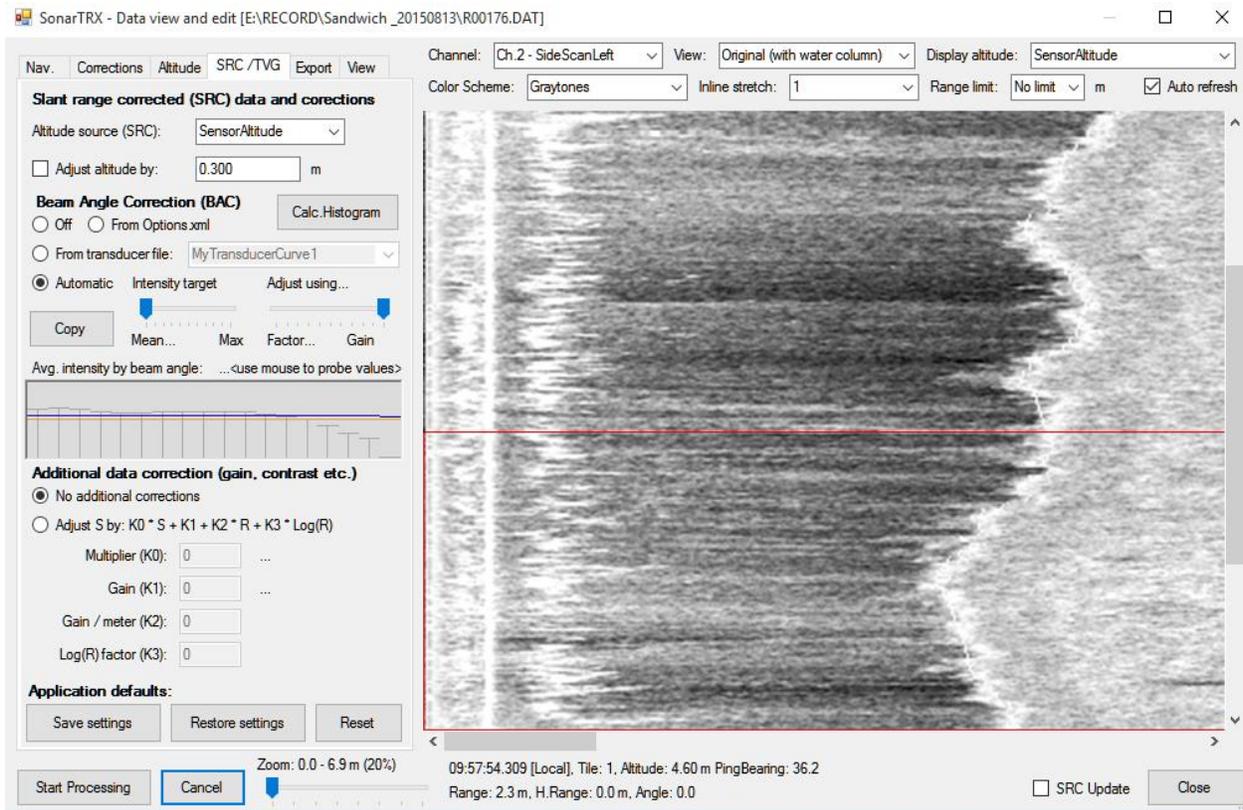


Figure 4-3. Slant range and beam angle correction window.

- Click on Start Processing.
- Click on Close.
- On the Main Menu, select Create Mosaic.
- Select the Parent Folder for Mosaics.
- Use the Default Mosaic Name.
- Click on the Sonar Mosaic Settings tab. Use the settings in Figure 4-4.
 - Image resolution may need to be adjusted for very large files.

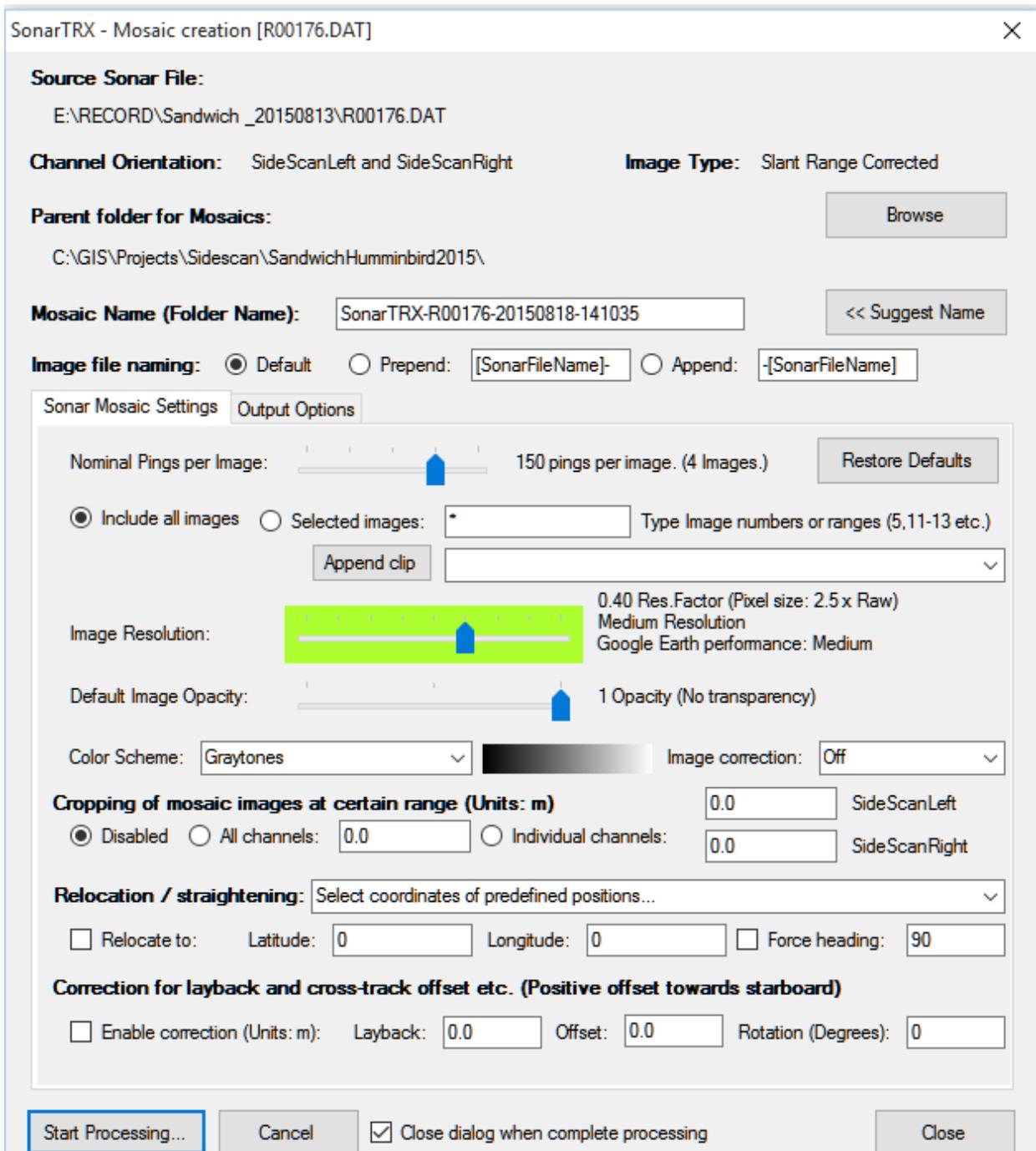


Figure 4-4. Create Mosaic, Sonar Mosaic Settings tab.

- Click on the Output Options tab. Use the settings in Figure 4-5.

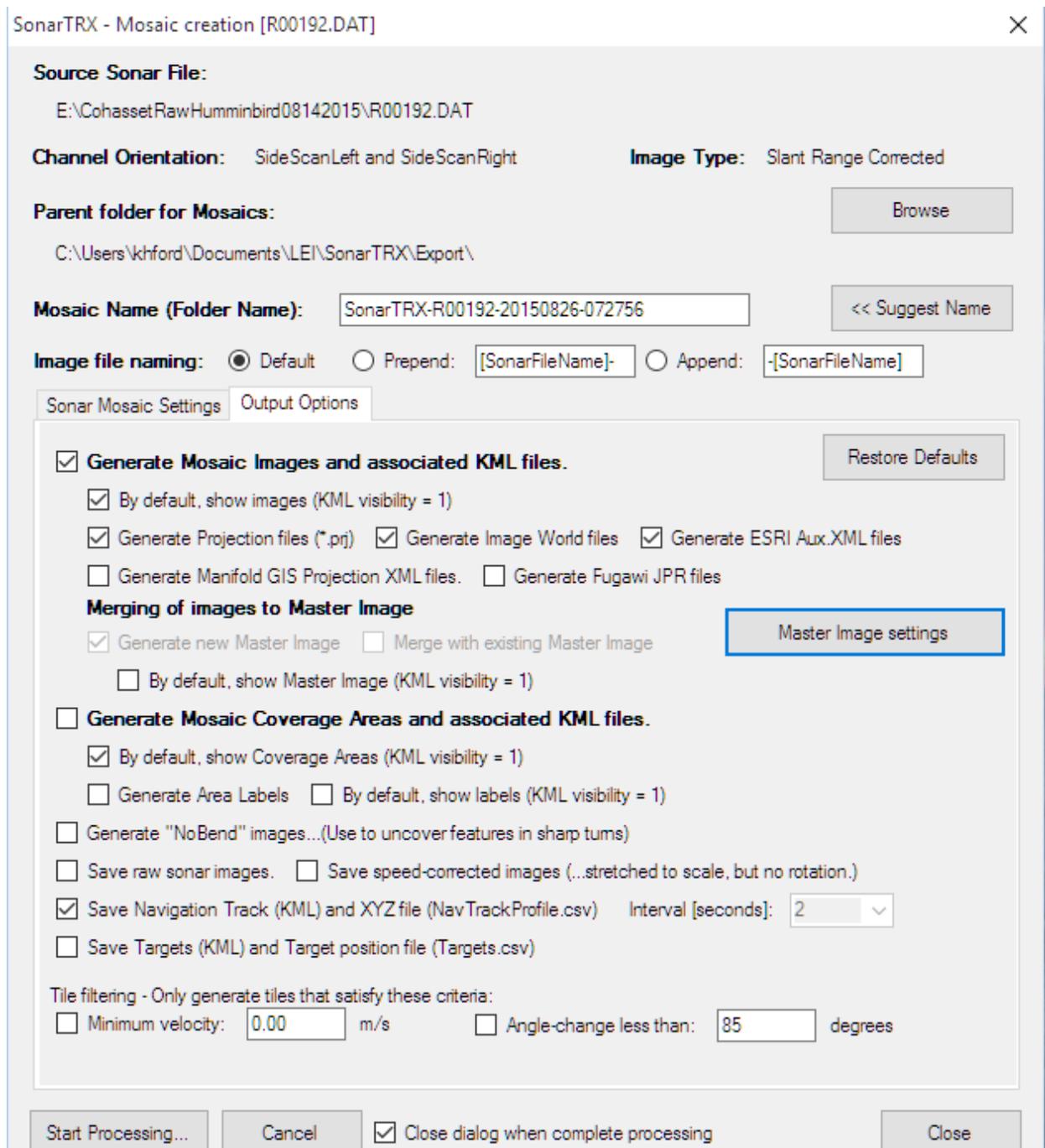


Figure 4-5. Create Mosaic, Output Options tab.

- Click on the Master Image Settings button. Use the settings in Figure 4-6.

SonarTRX processes each line file to a set of smaller tiles. The Master Image creates a mosaic of those smaller tiles so each line file is a single GeoTIFF/shapefile for ease of use in Google Earth and ArcGIS.

Master Image Options ✕

No Master Image
 Write images to existing Master Image (geo-referenced) Browse

Create new Master Image Browse

...

Geodetic boundary - center of perimeter pixels (new image)

Get Geodetic boundary from image tiles Manually define boundary

	Minimum	Maximum		Minimum	Maximum	
Latitude:	42.245563349	42.246331679	>>	Latitude:	40.662421125	40.687267255
Longitude:	-70.782654646	-70.778123675		Longitude:	-69.535481770	-69.510538078

Image resolution parameters (new image)

Maximum number of pixels in any direction:

Pixel size relative to image tile pixels [factor]: x 0.0477 [m]

Absolute pixel size [m]:

Resulting image properties:

		Minimum	Maximum
Size [W x H pixels]	7848 x 1792 (14.1 MP)	Latitude:	42.24556335 42.24633168
Pixel size [m]	0.048 x 0.048	Longitude:	-70.78265465 -70.77812367

Figure 4-6. Master Image Options.

- Click OK.

5.2. Analyzing Sonar Data

5.2.1. Habitat types

The primary program used for interpreting habitat types is ArcGIS. First, sonar mosaics and groundtruthing points are imported into ArcGIS. Baseline data, in particular aerial photography and NOAA charts, are imported into the project. A new polygon file is created and turned on for editing. The interpreter uses the available information to interpret boundaries between different habitat types evident in changes the backscatter signal in the sonar mosaic. These boundaries are drawn into the new polygon file. An attribute column is created in the polygon file to identify the habitat type.

To be added: discuss boundary snapping/topology, scale, and the standard habitat types that should be used for the habitat description.

5.2.2. Target recognition

Describe analysis to identify targets.

6. Data Management and Products

6.1. Data Filing and Organization

6.1.1. Raw and Processed Survey Data

6.1.1.1. *In the Field*

All raw survey data will be stored on the local computer (Klein) or SD drive (Humminbird) until the following day when the data will be copied to the V drive. For multiple day surveys, the data must be backed up nightly to an external hard drive. Once the multiple-day survey is complete, all raw data should be copied to the V drive and removed from the field computer, SD drive, and/or external drive.

6.1.1.2. *In the Office*

All raw survey data will be stored on the V drive under the Habitat Folder according to the following naming convention: V:\Habitat\[Project Name-YY]\[Project Name]Raw[SonarUnitName][MMDDYYYY]

Copies of the raw data can be transferred to the hard drive of the processing computer. Once processed, all processed survey data will be stored on the V drive under the Habitat Folder according to the following naming convention: V:\Habitat\[Project Name-Year]\[Project Name]Processed[SonarUnitName][MMDDYYYY]

6.1.1.3. *Archives and Backups*

The raw and processed data will be backed up by EEA IT according to its backup schedule for the V drive. The backup procedure is currently not published but a daily onsite backup was described by Bob Sigren, EEA IT. It will also be backed up to an external hard drive immediately after a survey is complete and after any project updates are complete . The external drive will be stored offsite (Duchaine Boulevard storage building).

6.1.2. Interpreted Data

6.1.2.1. *Working Files*

Copies of the raw data can be transferred to the hard drive of the processing computer. These files should be placed in a file location convenient to the person doing the processing. All working files, including Google Earth and ArcGIS files, should be placed in W:\Habitat Project\Habitat Research\[Project Name-Year]\GIS.

6.1.2.2. *Long-term storage*

Once a survey is completed, all interpreted survey data will be stored as a Map Package on the V drive under the Habitat Folder according to the following naming convention: V:\Habitat\[Project Name-Year]

The Map Package should be generated such that it can be sent to a potential user and opened with all interpreted files, the sonar mosaic, groundtruthing points, and relevant baseline files intact.

6.1.2.3. *Archives and Backups*

These data will be backed up by EEA IT according to its backup schedule for the V drive. The backup procedure is currently not published but a daily onsite backup was described by Bob Sigren, EEA IT. It will also be backed up to an external hard drive immediately after a survey is complete and after any project updates are complete . The external drive will be stored offsite (Duchaine Boulevard storage building).

6.1.3. Reports

A Cruise Report will be generated for every field day or set of field days dedicated to imaging a single survey area. The Cruise Report will be placed in W:\Habitat Project\Habitat Research according to the following naming convention: [Project Name-Year]\CruiseReportMMDDYY with the date referring to the date of the survey or the last date of a multiple-day survey.

Final Project Reports will be generated on a per-project basis and placed in W:\Habitat Project\Habitat Research according to the following naming convention: [Project Name-

Year]\FinalReportMMDDYYYY. The date refers to the date the final report was finished. Whenever possible, final reports will be submitted to the DMF Technical Report series.

Resolution

http://www.emodnet-seabedhabitats.eu/pdf/MeshA_ROG_Sidescan_Sonar_v4.0.pdf

The resolution in the along-track direction, Δ_{rx} , measures the resolution parallel to the line of travel. It will be strongly dependent on the horizontal beam width, θ_{hx} , and range, R , and can be expressed as:

$$\Delta_{rx} = \theta_{hx} \cdot R$$

According to this expression, the along-track resolution of a sonar, working under the same operational conditions, degrades with distance to the transducer (Fig. 7). Therefore, two objects will be detected as separated entities if they are separated by a distance which is less than the spread of the sonar beam Δ_{rx} at that range.

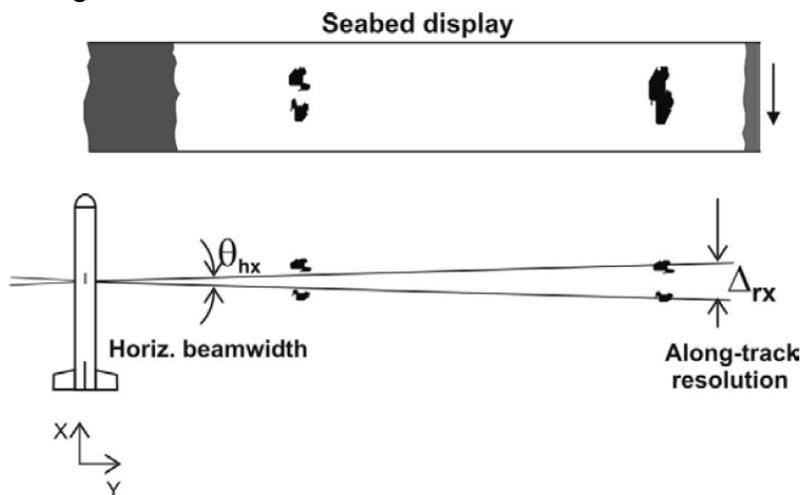


Figure 7- The along-track resolution of a sidescan sonar is dependent on the horizontal beamwidth and the slant range. The resolution improves at lower depths.

The Klein has a 0.21 degree horizontal beam width in the high res (455 kHz) channel. At 50 meter range that's 10.5 cm resolution

At 70 meter ranges that's 14.7 cm resolution

The across-track resolution Δ_{ry} (Fig. 8), is defined as the minimum distance between two objects perpendicular to the line of travel that can be distinguished as separated entities in the sonar image.

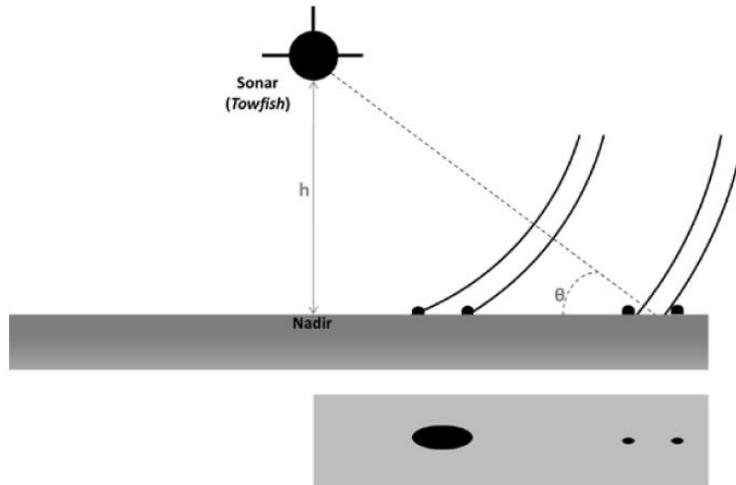


Figure 8- The across-track resolution of a sidescan sonar is dependent on the grazing angle θ and the pulse length T (after Mazel, 1985).

The pulse length, T , is the overriding operational parameter determining this resolution. As the acoustic wave direction is oblique to the seabed, this resolution can be expressed as:

$$\Delta_{ry} = \frac{T \cdot c}{2} \cdot \sec \theta$$

where θ is the grazing angle.

Additionally, to ensure full coverage in the swath area, no gaps between ensonified areas from two successive pings should exist (Blondel, 2009). This complete coverage condition depends on the transducer length, L , the vessel speed, v , and the ping rate, f_p . The ping rate can be calculated by the sound velocity in water, c , and the selected range, R (the theoretical sonar range resolution, across-track in the case of sidescan sonar):

$$f_p = \frac{c}{2 \cdot R}$$

For a given transducer length, L , a working ping rate (determined by the selected range), allows a complete coverage (without gaps) when a maximum vessel speed, v_{max} , is not exceeded:

$$V_{\max} = L \cdot f_p = \frac{L \cdot c}{2 \cdot R}$$

A short pulse will produce a thinner spatial pulse length, resulting in a higher spatial resolution, whilst a longer pulse will be less sensitive to the background noise, resulting in improved range performance. As a consequence, for greater seabed depths, ping rates must decrease to cope with longer range scales R involved. In such cases, the operator can be forced to slow down the tow speed to maintain total coverage along the swath.

6. Appendix

6.1. Klein 3000 Specifications Sheet

These images were copied from the pdf available at the Klein website:

http://www.kleinmarinesystems.com/PDF/Klein_System_3000_rev0216.pdf Accessed 11/7/2016

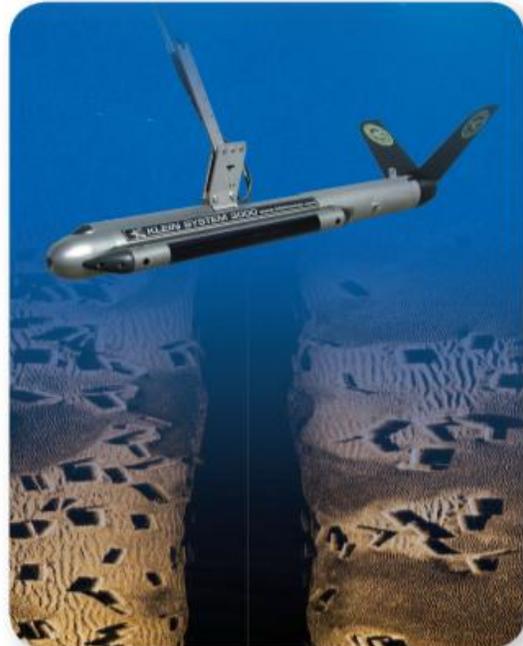


Digital Side Scan Sonar:

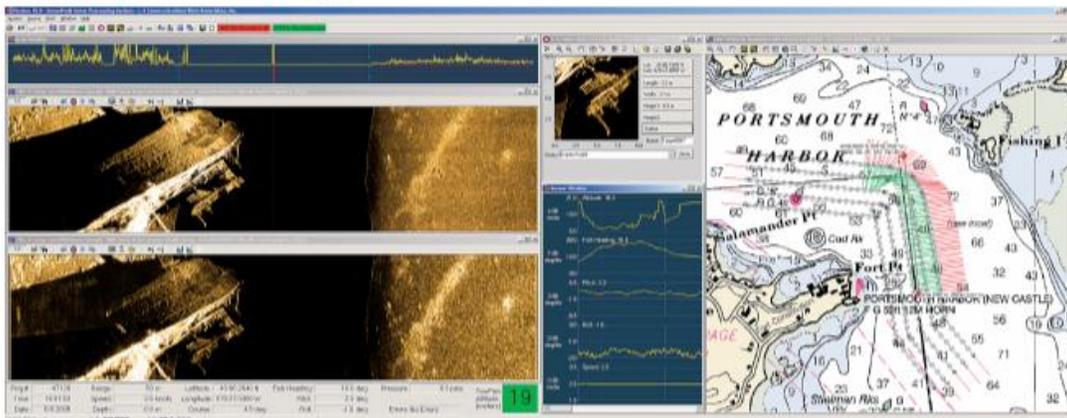
The Klein System 3000 presents the latest technology in digital side scan sonar imaging. The simultaneous dual-frequency operation is based on new transducer designs, as well as the high-resolution circuitry recently developed for the Klein multi-beam focused sonar. The System 3000 performance and price is directed to the commercial, institutional and governmental markets.

Key Features:

- Advanced signal processing and transducers produce superior imagery
- Cost-effective, affordable
- PC-based operation with SonarPro® software, dedicated to Klein sonars
- Small, lightweight and simple designs - easy to run and maintain
- Easily adapted to ROV's and custom towfish
- Meets IHO & NOAA Survey specifications



The Difference Is In The Image



SYSTEM 3000 SIDE SCAN SONAR



DUAL-FREQUENCY SINGLE BEAM SONAR

Specifications:

System 3000 Towfish	
Frequencies	100 kHz (132 kHz, ± 1% actual) 500 kHz (445 kHz, ± 1% actual)
Transmission Pulse	Tone burst, operator-selectable from 25 to 400 µsecs; Independent pulse controls for each frequency
Beams	Horizontal: 0.7° @ 100 kHz 0.21° @ 500 kHz Vertical: 40°
Beam Tilt	5°, 10°, 15°, 20°, 25° down, adjustable
Range Scales	15 settings - 25 to 1,000 meters
Maximum Range	600 m @ 100 kHz 150 m @ 500 kHz
Depth Rating	1,500 m standard; other options available
Construction	Stainless Steel
Body Length	122 cm (48 in)
Body Diameter	8.9 cm (3.5 in)
Weight	29 kg (63.9 lbs) in air
Standard Sensors	Roll, Pitch, Heading
Options	Magnetometer, pressure sensor, acoustic positioning, sub-bottom profiler
Transceiver Processor Unit (TPU)	
Operating System	VxWorks® with custom application
Basic Hardware	Splash-Proof 2 (SP2) TPU
Outputs	100 Base-Tx, Ethernet LAN
Navigation Input	NMEA 0183
Power	120 watts @ 120/240 VAC, 50/60 Hz (includes towfish)
Interfacing	Interfaces to all major sonar data processors
Options	19-in rack mount TPU
Tow Cable	
Klein offers a selection of coaxial, Kevlar® reinforced, lightweight cables, and interfaces to fiber optic cables. All cables come fully terminated at the towfish end.	

Klein Sonar Workstation	
Operating System	Windows
Sonar Software	SonarPro®
Data Format	SDF or XTF or both, selectable
Data Storage	Internal Hard Drive, CD/DVD-RW
Hardware	Industrial PC
Options	Optional Waterproof Laptops
SonarPro® Software	
Custom-developed software by users and for users of Klein Side Scan Sonar Systems operating on Windows 7. Field-proven for many years. SonarPro® is a modular package combining ease of use with advanced sonar features.	
Basic Modules	Main program, data display, information, target management, navigation, data recording & playing, and sensor display.
Multiple Display Windows	Permits multiple windows to view different features as well as targets in real-time or in playback modes. Multi-windows for sonar channels, navigation, sensors, status monitors, targets, etc.
Survey Design	Quick and easy survey set up with ability to change parameters, set tolerances, monitor actual coverage and store settings.
Target Management	Independent windows permitting mensuration, logging, comparisons, filing, classification, positioning, time & survey target layers, and feature enhancements. Locates target in navigation window.
Sensor Window	Displays all sensors in several formats (includes some alarms) and responder set up to suit many frequencies and ping rates.
Networking	Permits multiple, real time processing workstations via a LAN including "master and slave" configurations.
"Wizards"	To help operator set up various manual and default parameters.
Data Comparisons Real Time	Target and route comparisons to historical data.

Cleared for public release. Data, including specifications, contained within this document are summary in nature and subject to change at any time without notice at Klein Marine Systems' discretion. Call for latest revision. All brand names and product names referenced are trademarks, registered trademarks, or trade names of their respective holders. SonarPro® is a registered trademark of Klein Marine Systems, Inc. 2/16

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6.2. Humminbird 698 Specifications Sheet

Display Size - Diagonal: 5"	i-Pilot Link: Not Supported
Display Pixel Matrix: 480H x 640V	HD Radar: Not Supported
Display Type: Color TFT	NMEA 2000: Not Supported
Display Colors Grayscale: 256 Colors	5 Port Expansion Module: Not Supported
Sonar Standard: Side Imaging/Down Imaging/DualBeam PLUS	WeatherSense: Not Supported
Standard Sonar Coverage: 20°, 60° & (2) 85° @ -10db (Total of 180°)	Precision GPS: Included
Standard Sonar Frequency: 200/83/455 kHz	Heading Sensor GPS: Not Supported
Sonar Optional: None	PC Connect: Optional
Target Separation: 2.5"	External GPS Receiver: Not Supported
Power Output RMS: 500 Watts	AS Interlink: Not Supported
Power Output Peak to Peak: 4000 Watts	AIS Compatability: Not Supported
Depth Capability: 100 ft (SI/DI), 1500 ft	SwitchFire Sonar: Included
Temperature: Built In Transducer	Screen Snap Shot: Included
Speed: GPS Speed Included	Sonar Recording: Included
Backlight: LED	Humminbird PC: Included
Unit Size - Gimbal Mount: 6.9"W x 7.5"H x 4.5"D	Upgradable Internal Software: Included
Mount A Type: Quick Disconnect	Split Screen Zoom: Included
Unit Size - Indash Mount: 6.9"W x 5.4"H x 1.25"D	Split Screen Bottom Lock: Included
Mount B Unit Size2: Optional In-Dash	3D Chart View: Included
Mounting Options: Quick Disconnect or Optional In-Dash	Large Digits View: Included
Transducer Standard: XNT 9 SI 180 T	Wide/Narrow Cone Split Screen: Included
Transducer Mounting: Transom	Custom View Selections: Included
HD Side Imaging Sonar Coverage: Total 180°	Custom Digital Readout: Included
Power Input: 10-20 VDC	View Preset Keys: Included
Power Draw: 615 mA	Temperature Graph: Not Supported
GPS Receiver: Included	Temperature Alarm: Included
GPS Tracking: Included	Freeze Frame: Included
GPS Chartplotting: Included	Instant Image Update: Included
Waypoints, Routes, Tracks/Points: 2,500, 45, 50/20,000	Mark Structure on Sonar: Included
Humminbird Mapping: Optional	Selective Fish ID+: Included
Navionics+: Optional	Real Time Sonar: Included
Navionics Platinum+: Not Supported	Triplog: Included
Platinum Capable: Not Supported	X-Press Menu System: Included
C-Map 4D: Not Supported	Card Reader Available: Yes
360 Imaging: Not Supported	# Card Slots: 1

6.3. Humminbird 999 Specifications Sheet

Display Size - Diagonal: 8"	i-Pilot Link: Optional
Display Pixel Matrix: 800H x 480V	HD Radar: Optional
Display Type: Color TFT	NMEA 2000: Optional
Display Colors Grayscale: 65,000 Colors	5 Port Expansion Module: Optional
Sonar Standard: HD Side Imaging/HD Down Imaging/DualBeam PLUS	WeatherSense: Not Supported
Standard Sonar Coverage: 20°, 60°, (2) 86° & (2) 55° @ -10db (Total of 180°)	Precision GPS: Included
Standard Sonar Frequency: 200/83/455/800/50* kHz	Heading Sensor GPS: Optional
Target Separation: 2.5"	PC Connect: Optional
Power Output RMS: 1000 Watts*	External GPS Receiver: Optional
Power Output Peak to Peak: 8000 Watts*	AS Interlink: Not Supported
Depth Capability: 150 ft SI/DI, 1500 ft, 3000 ft*	AIS Compatability: Optional
Temperature: Built In Transducer	SwitchFire Sonar: Included
Speed: GPS Speed Included	Screen Snap Shot: Included
Backlight: LED	Sonar Recording: Included
Unit Size - Gimbal Mount: 11.25"W x 6.75"H x 4.25"D	Upgradable Internal Software: Included
Mount A Type: Gimbal Mount	Split Screen Zoom: Included
Unit Size - In-Dash Mount: 10.75"W x 6"H x 2.5"D	Split Screen Bottom Lock: Included
Mount B Unit Size2: Optional In-Dash	3D Chart View: Included
Mounting Options: Gimbal or Optional In-Dash	Large Digits View: Included
Transducer Standard: XHS 9 HDSI 180 T	Wide/Narrow Cone Split Screen: Included
Transducer Mounting: Transom	Custom View Selections: Included
HD Side Imaging Sonar Coverage: Total 180°	Custom Digital Readout: Included
Power Input: 10-20 VDC	View Preset Keys: Included
Power Draw: 780 mA	Temperature Graph: Included
GPS Receiver: Included	Temperature Alarm: Included
GPS Tracking: Included	Freeze Frame: Included
GPS Chartplotting: Included	Instant Image Update: Included
Waypoints, Routes, Tracks/Points: 2,750, 45, 50/20,000	Mark Structure on Sonar: Included
Humminbird Mapping: Optional	Selective Fish ID+: Included
Navionics+: Optional	Real Time Sonar: Included
Navionics Platinum+: Optional	Triplog: Included
Platinum Capable: Optional	X-Press Menu System: Included
C-Map 4D: Not Supported	Card Reader Available: Yes
360 Imaging: Optional	# Card Slots: 2

APPENDIX E. DMF/MASSBAYS STANDARD OPERATING
PROCEDURE FOR CITIZEN SCIENCE EELGRASS MONITORING

Standard Operating Procedure

Massachusetts Division of Marine Fisheries / MassBays National Estuary Partnership Standard Operating Procedure for Citizen Scientist Eelgrass Monitoring

Points of Contact: Jill.Carr@mass.gov, Tay.Evans@mass.gov

V.1., Created by T. Evans and J.Carr, 08/2018

V.2., Edited to update shoot collection methods (draft), 2019

V.3., Edited by J.Carr and F. Schenck for integration into iSeaGrass web app, 08/2020

V.4., Edited by F. Schenck for integration into iSeaGrass web app 07/2021

OBJECTIVE: Monitoring of eelgrass presence and condition. Sampling is performed according to the following procedure that documents presence/absence, percent cover, sediment, and individual shoot measurements.

I. GEAR LIST:

Shallow draft vessel

Coast guard required safety gear

Boat anchor

GPS unit with accuracy of 4 m or better

Mobile phone or tablet with access to iSeaGrass web app

Monitoring Kit contents:

Clipboard, datasheets, pencils, laminated SOPs

Underwater Splashcam digital camera, reel, and case; charged, with SD card

0.25 m² PVC quadrat drop-frame, line and float

FujiFilm topside point-and-shoot camera, charged, with SD card

Plexiglass site labeler

Secchi disk with line

Metric measuring tape

View Scope bucket

Small Danforth anchor and small mushroom anchor, line and float

Misc: zip ties, duct tape, dry erase marker, absorbent towels

Optional: mask, snorkel and fins for in-water shoot collection

II. SUMMARY

At all stations:

- Navigate to the station using GPS coordinates and anchor the boat, record actual coordinates and other topside information.
- Record secchi disk measurements at two locations on the sunny side of the boat using the view bucket.
- At the four “corners” of the boat, use the drop-frame to take a sample picture and estimate the percent cover within the quadrat using the visual guides.
- Review data to ensure accuracy. If there are any changes, cross out the original and initial the change (if using paper datasheets).
- If not an “indicator” station, raise the anchor and navigate to the next station.

Additional sampling at **indicator** eelgrass stations:

- At each of the four corners of the boat where eelgrass was observed, use the Danforth anchor or swim with mask and snorkel to take a bottom grab sample, collecting at least three shoots per sample.
- Identify the longest leaf from each shoot. Measure the leaves and estimate coverage of wasting disease and epiphytes, and record.
- Lay the shoots on the tote cover and fan the leaves, collect photos of the sample using the topside camera.
- Raise the anchor and navigate to the next station.

III. DETAILED METHODS:

1. Navigating to the station

- Volunteers navigate using their boat's GPS (or a hand held GPS unit, or cell phone if necessary) to get as close to the monitoring station as possible. Stations are defined as the area within a 10-m radius circle of the GPS location, accounting for boat swing and GPS error.
- Once on station, turn the boat into the wind or current, whichever is strongest. Anchor the boat by lowering the anchor off of the bow. Let out the necessary scope.

2. Data collection at all stations: Secchi disk

A Secchi disk is a weighted 20 cm diameter disk painted black and white with an attached line. Ideal weather conditions for accurate secchi data collection include sunny or partly sunny skies; calm winds (≤ 10 knots) and little to no chop (waves on the water). Collect secchi measurements between 10 am and 4 pm. Ideally, water level should be about 50% greater than the secchi depth so that it is viewed through the water column rather than against bottom-reflected light. This may not always be possible in shallow embayments that support seagrass. If the disk hits the bottom, record as such.

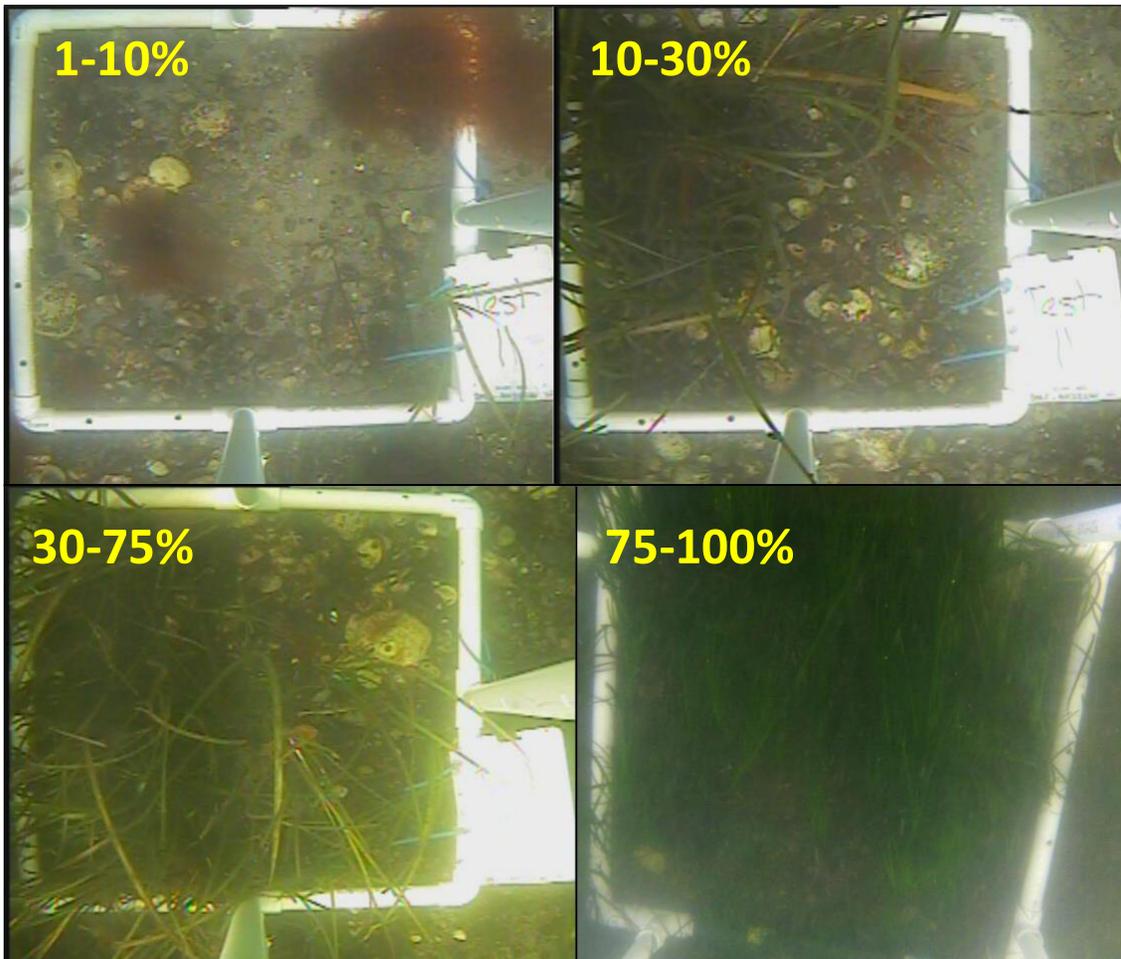
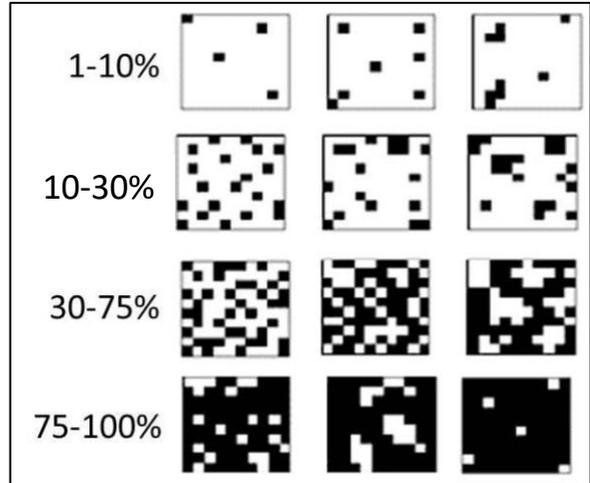
- Record the time, weather observations, water depth and other trip information.
- Remove your sunglasses, as they will give you an inaccurate reading (but be sure to wear regular corrective lenses if you need them).
- Unwind several meters of the Secchi disk rope from the holder.
- Lean over the sunny side of the boat if using a view bucket and submerge the bottom 1-2" of the bucket into the water. If not using a view bucket, use the shaded side of the boat.
- Another volunteer slowly lowers the secchi disk into the water until the viewer can no longer see it. Slowly raise the disk. When the secchi disk reappears, mark the rope at the surface of the water with a clothespin.
- Bring the secchi disk back on board and measure the length of the line from the disk to the clothespin location with your measuring tape and record. Repeat and record.
- If two different people will regularly be making secchi measurements, both should take the first few measurements to ensure that the results are similar.
- Useful website with tips: <https://www.nalms.org/secchidipin/>

3. Camera set up and operation: Follow the laminated camera guide included in the camera case.

4. Data collection at all stations: pictures and percent cover data

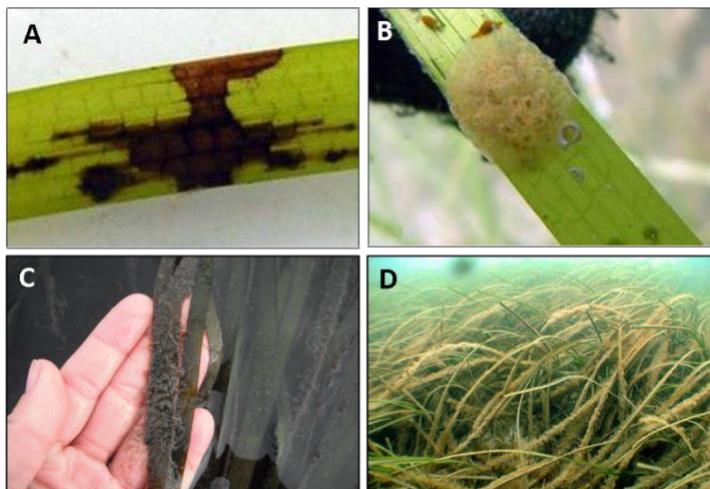
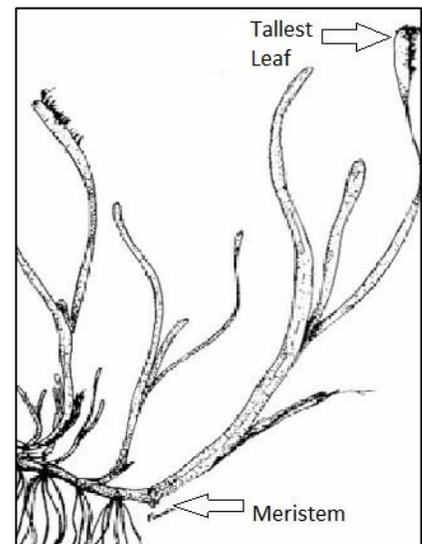
- Four samples will be collected off the four corners of the boat.
- Beginning on the windward and up-current side of the boat, with the camera on, lower the drop-frame over the side. Once it hits the bottom leave it there for several seconds to allow sediment to settle. View the camera screen to ensure the quadrat landed flat.

- Look at the monitor and ensure that the image is of the whole quadrat and the bottom (and/or eelgrass) is clearly visible. On the DVR unit, press the “OK” or “record” button to take a picture. If you are unsure if a picture was taken, press the “Preview” button on the DVR unit to view the last image captured.
- Record the timestamp from the picture.
- Record sediment type as mud, clay, sand, gravel and/or cobble (all that apply) and note other benthic characteristics (mussels, debris, algae or other observation).
- Estimate the percent cover of eelgrass using the following bins (**0%**, **1-10%**, **10-30%**, **30-75%**, **75-100%**) and the provided coverage guide (right).
- Repeat at the remaining 3 corners of the boat.
- If this is an indicator station, continue to step (5).



5. Additional data collection at **indicator** stations: Eelgrass length and width measurements, and stressor indices

- If eelgrass was present at a given corner of the boat, collect shoot samples by tossing the Danforth anchor out about 5 feet from the boat and gently dragging it several feet, attempting to collect at least three eelgrass shoots. Slowly pull it up, deploying again as necessary. This will be repeated at each of the four corners of the boat that contained eelgrass during the drop-frame sampling (e.g. if all four corners had eelgrass, then four shoot samples will be collected, each containing three shoots, totaling 12 shoots from that station). Alternatively, participants are welcome to snorkel for sample collection. This option requires the use of a personal mask, a boat which can accommodate entry and exit from the water, and a captain who is comfortable with participants swimming from their boat. If this option is used, the swimmer should safely free-dive down to the eelgrass and pick one shoot at a time by pinching the plant below its meristem (see figure below) and applying an upward pulling/twisting motion. Grabbing clumps of shoots should be avoided; as should grabbing from the leaves which can lead to plant damage and incomplete samples.
- From the sample, select three intact shoots and place the shoots on the white tote lid along the ruler, fanning the leaves. Use the FujiFilm topside camera to collect an overall photograph of the entire sample, with the ruler in view, as well as any close-up photographs of wasting disease, epiphytes, or other observations that are of interest.
- Identify the longest leaf in each of the three sample plants. Measure the length and width of the leaf using the measuring tape. Length is measured from the meristem to the leaf tip (see below), and width is measured across the widest part of the leaf. If the tallest leaf is broken indicate this with an asterisk (*) or in the notes. Record the measurements.
- Estimate cover of epiphytes (encrusting algae or tunicates) and wasting disease on the three leaf samples and assign none, low, med. or high (see two guides below).
- Discard plants overboard and repeat at remaining corners. (Note: If colleagues or scientists request sampling collection, samples should be placed in clean, clearly labeled zip-lock bags and stored on ice in a cooler until transfer to the requester).



Wasting disease (A) and epiphyte coverage (B-D) on eelgrass.
Photos from Cornell Cooperative Extension/SeagrassLI.org and @PLNReynolds

INDEX FOR MEASURING COVERAGE OF WASTING DISEASE AND EPIPHYTES

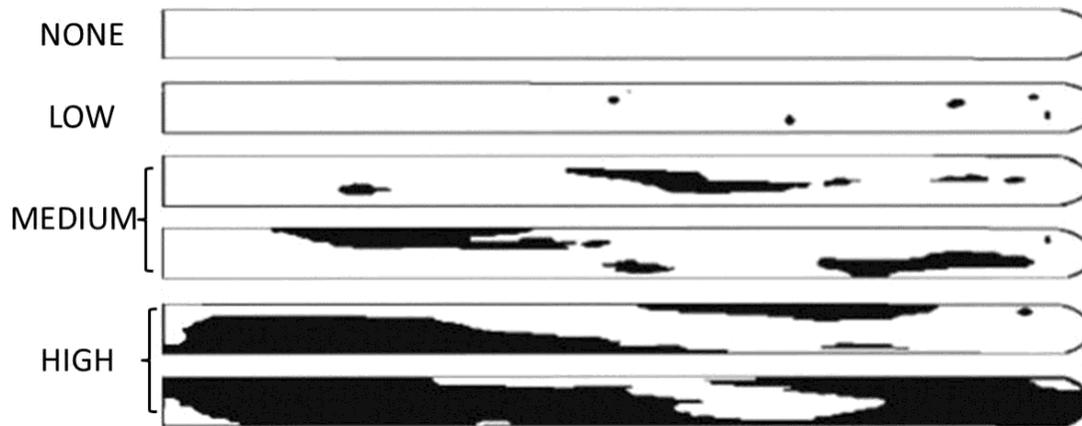


Image altered from Burdick et al. 1993.

6. Cleaning and storage

- At the end of each field day, inspect all equipment to ensure everything is accounted for and in similar condition to when it was received at the beginning of the day. If any items are missing, damaged, or altered in any way, note the change(s) and inform the organizer.
- Rinse all gear that came in contact with salt water, taking particular care with the camera and lowering frame. Soak the camera in a tub of warm water.
- Be careful not to allow any cables, connections, or electronic equipment from the waterproof box to come into contact with water. The two plugs attached to the camera cable reel must also remain clean and dry at all times.
- Inspect the camera case to make sure it has remained clean and dry after each use. If necessary, carefully clean that monitor screen with a paper towel. If water is present in the box, remove it as soon as possible with a dry paper towel and inspect all electronic equipment to ensure no damage occurred.
- Allow all gear to dry and store in a cool, dry place.
- Recharge batteries if needed, and give SD card to the organizer.
- If you collected data via the iSeagrass web app, use the button at the bottom of your trip screen to upload the data when your phone connects to the internet via cellular data or wifi.
- If you collected data via paper data sheets, give the data sheets to the organizer.

IV. iSeaGrass Web App User Guide

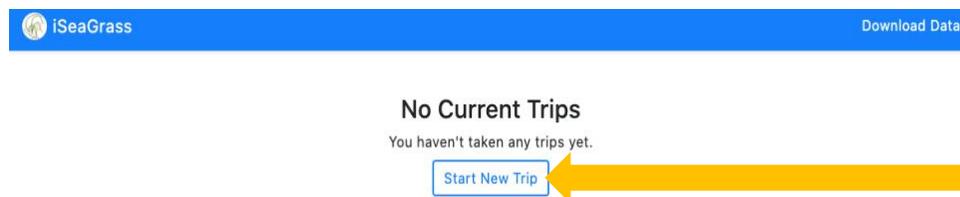
1. How to Collect Data

Step 1: At the beginning of the day, click on the 'Go to your trips' button.



Step 2: Click on the 'Start New Trip' button.

Note: If you collect over multiple days, start a new trip at the beginning of each day.



Step 3: Complete the fields in the 'Trip Details' section.

The screenshot shows the iSeaGrass application interface. At the top, there is a blue header with the iSeaGrass logo and a 'Download Data' button. Below the header, there is a navigation link '< Save and Back to trips'. The main section is titled 'Trip Details' and contains several input fields: 'Crew Members' with a 'Full name...' field, 'Trip Date' with a date picker set to '05/25/2021', and 'Boat Name' with an empty text field. A blue 'Add Station' button is located to the right of the 'Boat Name' field. Below these fields is a 'Stations' section with a light gray background, displaying 'No Stations' and a blue 'Add Station' link. At the bottom, there is an 'Actions' section with two buttons: a green 'Upload Trip Data' button and a red 'Delete This Trip' button. Three yellow arrows point to the 'Full name...', 'Trip Date', and 'Boat Name' input fields.

Step 4: Once you've navigated to a sampling station, click on either of the 'Add Station' buttons.

This screenshot is identical to the one above, showing the iSeaGrass 'Trip Details' form. In this version, two yellow arrows highlight the 'Add Station' buttons. One arrow points to the blue 'Add Station' button located to the right of the 'Boat Name' field. The second arrow points to the blue 'Add Station' link located in the 'Stations' section, below the 'No Stations' text.

Step 5: Start by filling out the fields in the station tab and move to the other tabs following the data collection protocol.

The screenshot shows the ISeaGrass app interface. At the top, there is a blue header with the ISeaGrass logo on the left and a 'Download Data' button on the right. Below the header is a navigation bar with a back arrow and the text '< Save and Back to Trip'. The main content area is divided into several sections. The first section is the 'Station' tab, which is currently active and shows a dropdown arrow with a green checkmark on the right. Below this are input fields for 'Station ID', 'Harbor', and 'Notes'. To the right of the 'Station ID' field is a checkbox labeled 'Indicator Station?'. Below the 'Station' tab is a list of other tabs: 'Location', 'Weather', 'Secchi Drop', and 'Drop Frames 0/4'. Each of these tabs has a right-pointing chevron, and a yellow arrow points to each chevron. At the bottom of the main content area is a green button labeled 'Save and Back to Trip'. Below this is a 'Settings' tab with a right-pointing chevron.

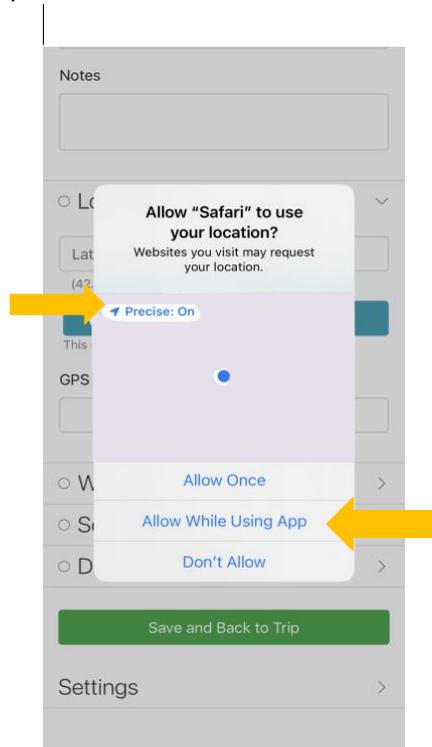
Step 6: Once all the fields have been completed click 'Save and Back to Trip'. Repeat for subsequent stations.

Note: Tabs where all fields have been completed will display green checks beside them.

The screenshot shows the ISeaGrass app interface after completing the station. The blue header and 'Download Data' button are still present. The navigation bar now shows a back arrow and the text '< Save and Back to Trip'. The 'Station Practice 1' tab is now selected and has a green checkmark on the left and a right-pointing chevron on the right. Below it are the other tabs: 'Location', 'Weather', 'Secchi Drop', and 'Drop Frames 4/4'. Each of these tabs now has a green checkmark on the left and a right-pointing chevron on the right. The 'Weather' tab is highlighted with a grey background. At the bottom of the main content area is a green button labeled 'Save and Back to Trip', with a yellow arrow pointing to it. Below this is a 'Settings' tab with a right-pointing chevron.

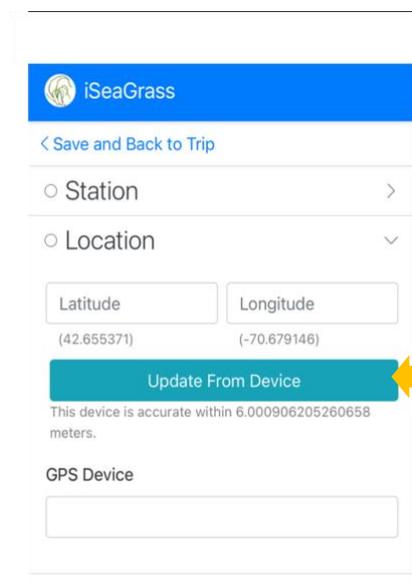
2. How to Collect Station Location from Device

Step 1: When you open the location tab you may be prompted to allow your default internet browser to use your location. Click the 'Allow While Using App' button. Also click on the precise location feature to turn it 'On'.



Step 2: Click on the 'Update From Device' button. The iSeaGrass App will automatically populate the 'Latitude' and 'Longitude' fields as well as the 'GPS Device' field.

Note: Device accuracy may improve while at the station and subsequent clicks on the 'Update From Device' button will override previously collected GPS coordinates for the station. At most locations the device should be able to obtain an accuracy within 10m.



3. How to Upload Data

Step 1: Once sampling has concluded for the day and you are connected to a Wi-Fi network, click on the 'Upload Trip Data' button.

The screenshot shows the iSeaGrass mobile application interface. At the top, there is a blue header with the iSeaGrass logo on the left and a 'Download Data' button on the right. Below the header, there is a navigation link '< Save and Back to trips'. The main section is titled 'Trip Details' and contains several input fields: 'Practice Seagrass', 'Full name...', 'Trip Date' (with a calendar icon), and 'Boat Name'. Below these fields is a section for 'Stations' with an 'Add Station' button and two listed stations: 'Station Practice 1' and 'Station Practice 2'. At the bottom, there is an 'Actions' section with two buttons: 'Upload Trip Data' (highlighted in green with a yellow arrow pointing to it) and 'Delete This Trip' (highlighted in red).

Upload Trip Data
Requires Internet. This will upload the current trip data to the server. You can upload multiple times if you want and only the most recent will be saved.

Delete This Trip
Remove this trip from your device. This is safe to do once you have uploaded the data.

APPENDIX F. DATASHEETS AND LOGS

Eelgrass survey metadata log

Site Name: _____
 Date: _____ / _____ / _____
 Equipment/Platform: _____
 Site Access: _____

Samplers: _____
 Survey Start Time: _____ a.m. / p.m.
 Survey End Time: _____ a.m. / p.m.
 GPS System: _____

Survey Type (check)		Environmental conditions	
Drone		Cloud Cover	%
Airplane		Wind Speed	kts
Satellite		Approx. wave height	ft
Side Scan Sonar		Turbidity (high/med/low)	
Photo Groundtruthing		Prev 24hr weather	
Diver		Time of low tide	am / pm
Other (describe below)		Sun angle	

Secchi samples (if collected)				
	1	2	3	4
Lat	_____	_____	_____	_____
Long	_____	_____	_____	_____
Secchi Depth (m)	_____	_____	_____	_____

Specs	
Flight altitude	_____ ft / m
# images collected	_____
spatial resolution	_____ ft / m
coverage over survey area	_____ % <i>to be determined post-survey for all methods</i>
spatial accuracy	_____ ft / m <i>to be determined post-survey for imagery</i>
Waves, clouds and clarity	_____ <i>to be determined post-survey for imagery</i>

Observations, comments, and corrective actions	Survey sketch (if applicable)

QAQC (check)	Survey lead: initial in QAQC box to verify that checks were made prior to leaving each station to ensure that all samples and data were collected; and that entries on data forms and labels are legible and free of errors.
---------------------	--

Diver datasheet

Site _____ Transect ID _____ Depth _____ Latitude _____ Longitude _____
 Date/Time _____ Transect Heading _____ ° Transect Start _____ / _____
 Diver _____ Transect Length (LAST SHOOT) _____ m Transect End _____ / _____
 Underwater vis. _____ m / ft Distance checked beyond _____ m

Qu ad	Meter marking	Eelgrass % Cover Bin											Canopy Height (cm)	Distribution Type			Algae Types	Photo (check)	Notes
		0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		<1m	1-5m	>5m			
1		0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		<1m	1-5m	>5m			
2		0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		<1m	1-5m	>5m			
3		0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		<1m	1-5m	>5m			
4		0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		<1m	1-5m	>5m			
5		0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		<1m	1-5m	>5m			
6		0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		<1m	1-5m	>5m			
7		0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		<1m	1-5m	>5m			
8		0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		<1m	1-5m	>5m			
9		0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		<1m	1-5m	>5m			
10		0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		<1m	1-5m	>5m			
11		0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		<1m	1-5m	>5m			
12		0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		<1m	1-5m	>5m			

QC Sample	Meter marking	Eelgrass % Cover Bin											Canopy Height (cm)	Distribution Type			Algae Types	Notes	
		0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		<1m	1-5m	>5m			
		0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		<1m	1-5m	>5m			

Transect Sketch/Notes

QAQC (initial) _____

Data Review Evaluation Form - Diver Surveys

This form documents data QA/QC review to assure data quality. All sites can be evaluated on the same form. Refer to Table 6 in QAPP, and completed survey logs and metadata logs.

Reviewer: _____

Site	Timing: sampled within 2 wks of other surveys (y/n)	Completeness Evaluation				Diver QC sample evaluation			Final Decisions			
		# Transects sampled	# Transects planned	# Quadrats sampled	# Quadrats planned	# quadrats with missing data	% cover same or within 1 bin of each other (y/n)	Canopy height difference	Distribution type, algae presence data match	Describe criteria violations	Corrective Actions Needed (Y/N; if Y describe)	Fitness for Use (Yes/No/Limited; if N or L, describe)
<i>Niles Beach</i>			3		36							
<i>Mingo Beach</i>			3		36							
<i>Swampscott Harbor</i>			3		36							
<i>Dorothy Cove</i>			3		36							
<i>Cohasset Harbor</i>			3		36							

criteria: all transects sampled

criteria: ≥ 80%

criteria: <10% missing

criteria: ≤ 20% RPD

criteria: must match

Reviewer Notes

Photointerpretation processing log

Scientist information

Photointerpreter Name: _____

Organization: _____

Survey Data Type: _____

Screen specifications

Make, model and screen diagonal size: _____

Display resolution*: _____

Bit Depth and Color Format**: _____

Coordinate reference system of map while conducting photointerpretation: _____

Notes on data exploration (spatial/spectral settings, etc):

Photointerpretation log, refer to rules in QAPP Table 11

Site	Date of Completion	Spatial Scale used when drawing polygons	Spectral settings when drawing polygons	Maximum distance threshold used when bridging neighboring patches	Describe problem areas or challenges	Polygon file name
Niles Beach						
Mingo Beach						
Swampscott Harbor						
Dorothy Cove						
Cohasset Harbor						

Was a point file of problem areas created and need PI review? If so, write the file name:

After comparison of two interpreter results:

Describe level of agreement between interpreters and process for generating a final polygon:

Is there anything else the QA/QC reviewers should know?

THANK YOU and GREAT WORK!

*Display resolution can be found in your computer Settings, under "Display" for Windows computers. The highest resolution is recommended, and is often 1920x1080.

**Advanced display options can show you your bit depth and color format

Imagery processing log

Scientist information

Image Processor's Name: _____
 Organization: _____
 Survey Data Type: _____
 Software Used: _____

Image processing log

Site	Spectral or Spatial Corrections Made	Processing Issues (drone and sonar: describe any lost image tiles or areas not able to be mapped)	Final mosaic file name & size
Niles Beach			
Mingo Beach			
Swampscott Harbor			
Dorothy Cove			
Cohasset Harbor			

Evaluation of horizontal accuracy: for satellite, aerial and drone imagery, check 10 locations visible in the imagery datasets against known coordinates using 2021 USGS Color Orthoimagery as a reference dataset (not applicable to sonar data). Record differentials below, and average horizontal accuracy on the metadata log for each survey type.

1 _____	6 _____
2 _____	7 _____
3 _____	8 _____
4 _____	9 _____
5 _____	10 _____

Other comments

Attach any additional processing information to this sheet.

Photointerpretation training & evaluation log

Trainer: _____
 Trainee Name(s): _____
 Trainee Organization: _____
 Date: _____

Training Content	Completed	Comment
Overview of concepts: image resolution, accuracy, horizontal error, projections, datums, image quality		
Examples of photointerpretation considerations (tone, color, contrast, texture, shadows, shape)		
Details about the survey method used in the field and its limitations		
Overview of ArcGIS tools and workflow for creating, saving and sharing polygons		
Discussion of rules to follow during interpretation (QAPP Table 11)		
Demonstrations of different interpretation scenarios		
Supervised practice using example imagery		

Evaluation using a test dataset	Pass/Fail	Comment
Photointerpreters demonstrated ability to navigate and use the necessary ArcGIS tools		
Photointerpreters showed proficiency applying the rules in QAPP Table 11		
Photointerpreters worked together to solve discrepancies		
Interpretation of test dataset was similar to professional results (calculated polygon areas have < 20% RPD*)		

Overall Pass/Fail or corrective steps: _____

*Relative Percentage Difference = $(|Num1-Num2|/((Num1+Num2)/2)) \times 100$

APPENDIX G. DATA MANAGEMENT PLAN

Dataset	File types	Data tools	Processing plan	QA/QC	Archive & Access plan
Site Selection	Shapefiles (.shp) within master geodatabase	ArcGIS Desktop 10.6 or better	Overlay relevant layers, manually select study sites, create new point file of sites	Poll steering committee on appropriate site selection layers. Ensure use of compatible coordinate systems, projections and datums	Archive on Commonwealth network and back up on project external hard drive
Survey imagery rasters	Geo-referenced image files (GeoTIFF, JPEG) within master geodatabase	SonarTRX (side scan); GeoImage (aerial); Drone2Map (drone); ArcGIS Desktop 10.6 or better (all)	Create mosaics of survey imagery, performing geographic rectification where needed <i>See note 1</i>	Ensure use of compatible coordinate systems, projections and datums. Check equipment compass, range, and connectivity prior to surveys. Use ground control points where necessary	Archive raw imagery tiles and mosaicked rasters to Commonwealth network, ArcGISOnline (or similar), and back up on project external hard drive
Field groundtruthing points and images	Excel (.xls) spreadsheet of groundtruthing locations and eelgrass data (density, % cover, height); JPEGs of underwater photography	Microsoft Excel, ArcGIS Desktop 10.6 or better	Transcribe field data sheets to spreadsheet. Create point file of survey locations and embed corresponding underwater photos at each location	Ensure use of compatible coordinate systems, projections and datums. Check equipment compass, range, and connectivity prior to surveys. Second reviewer checks all data entry for errors	Archive on Commonwealth network, and back up on project external hard drive
Eelgrass meadow delineations	Shapefiles (.shp) and kml (.kml)	ArcGIS Desktop 10.6 or better, GoogleEarth	Manually digitize eelgrass meadows detected in each survey method	Ensure use of compatible coordinate systems, projections and datums. Second interpreter checks all delineations and flags questionable areas for Data Manager	Archive on Commonwealth network, ArcGISOnline (or similar), and back up on project external hard drive. Available to public on MassGIS, Oliver, Storymap, or similar
Eelgrass meadow extrapolations	Shapefiles (.shp) and kml (.kml)	ArcGIS Desktop 10.6 or better, GoogleEarth	Improve delineations with groundtruthing data, extrapolate new meadow edge for each survey method. Extend to other meadows	Ensure use of compatible coordinate systems, projections and datums	Archive on Commonwealth network, ArcGISOnline (or similar), and back up on project external hard drive. Available to public on MassGIS, Oliver, Storymap, or similar
Detection error matrices	Excel spreadsheets (.xls), converted to images for reporting	Microsoft Excel, R	Identify number of sites where eelgrass is detected at various densities for each survey method, determine number of accurate detections and missed detections (errors)	Use queries in GIS to isolate accurate detections and minimize user error. Manually double check all results. Ensure use of compatible coordinate systems, projections and datums	Archive on Commonwealth network and back up on project external hard drive. Available to public in final project reporting

¹All geospatial products will be produced with a horizontal datum/projection of NAD1983 (2011) State Plane Massachusetts Mainland FIPS 2001, Meters. Quality assurance of all imagery includes ensuring no loss of tiles, proper mosaicking of tiles, and well-blending of tiles with their neighbors. If any imagery does not fit the project's quality standards, it will be flagged and reported as such, and imagery will either be recaptured if possible or will be used with clearly stated limitations.